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Soil Conductivity Investigation Results

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U.S. Department of Energy Grand Junction Office

Calculation Cover Sheet

Calc. No. Moab–11–2002–02–05–00 **Discipline:** Hydrogeology **Number of Sheets:** 3

Project:
Moab Ground Water

Site:
Moab, Utah

Feature:
Soil Conductivity Investigation Results

Sources of Data:
Field Investigations 2002

Sources of Formulae & References:

U.S. Department of Energy (DOE), 2002a. *Groundwater and Tailings Pile Characterization Activities to Support the Plan for Remediation Work Plan*, GJO–2002–337–TAR, prepared for the U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado, June.

U.S. Department of Energy (DOE), 2002b. *Characterization of Groundwater Brine Zones at the Moab, Utah, UMTRA Project Site,* GJO–MOA 1.9-2-3, prepared for the U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado.

Preliminary Calc. ☐ **Final Calc.** ☒ **Supersedes Calc. No.** ______________

Rev. No.	Revision	Calculation by	Date	Checked by	Date	Approved by	Date
		Karl D. Karp	1-14-03	H. Smith	1-14-03	Tally Wyatt	1/15/03

1.0 Purpose

The purpose of this calculation set is to provide the results of soil conductivity measurements performed at the Moab Project Site from June 21 through July 13, 2002. All electrical conductivity measurements were performed in accordance with methods described in *Groundwater and Tailings Pile Characterization Activities to Support the Plan for Remediation Work Plan* (DOE 2002a).

Electrical soil conductivity (or resistivity) logging is a method that is used to determine lithology of unconsolidated materials. In special situations, conductivity logging can determine the presence of soluble and high ionic strength constituents in ground water, such as brine solutions. Soil conductivity logging was used at the Moab Project Site to evaluate the interface between the upper fresh water zone and a deeper brine zone in the alluvial aquifer. Electrical conductivity measurements were performed at 11 locations using a Geoprobe Systems, Inc., SC400 conductivity probe. A description of the probe and its corresponding data acquisition system is presented in Attachment 1.

2.0 Direct-Push Rig

ConeTec, Inc., used a direct-push Marl (M5T) Rhino rig to advance the SC400 conductivity probe into the subsurface at each measurement location. Pictures of the M5T Rhino rig are presented in Attachment 2.

3.0 Soil Conductivity Measurement Locations

A location map showing where each soil conductivity measurement was performed with respect to the Moab Project Site is provided as Attachment 3.

State plane survey coordinates for each of the 11 borings are summarized in the coordinate location table provided as Attachment 4. The coordinate location table also provides the surveyed land surface elevation, the date each test was conducted, and the total depth of each test.

4.0 Soil Conductivity Profiles

Electrical conductivity as a function of depth for each test location is provided in Attachment 5. Lithology obtained from the SMI–PW–01 well cluster, approximately 11 feet away, is provided on the electrical conductivity profile for location 358. Lithology information is not available for the other probed locations. Conductivity profiles combined with multiple test locations and plotted at 2,000 millisiemens per meter (mS/m) and 400 mS/m full scale are provided in Attachment 6. These profiles are also included on the map in Attachment 3.

5.0 Water Samples

Ground water grab samples were collected at discrete depth intervals from locations 362 and 364 using the Hydropunch sampling method and analyzed by the Grand Junction Office Environmental Sciences Laboratory for ammonia, chloride, density, specific conductance, sulfate, total dissolved solids (TDS), and uranium. Results are presented in Attachment 7.

6.0 Preliminary Findings

Reproducibility of the soil conductivity method was evaluated in the field by performing a duplicate measurement at test location 367. However, a true duplicate measurement could not be performed at exactly the same location because the conductivity probe needs to be in direct contact with the soil. Probing the first hole a second time to obtain the duplicate measurement would result in an inadequate contact between the hole and the conductivity probe. Therefore, the second measurement location was offset a few feet from the first measurement location. Comparisons between the first measurement (Test 1) and the duplicate measurement (Test 2) are presented in Attachment 8. Excellent reproducibility in the method is evidenced by the high coefficient of determination (r) value of 0.91 shown in the regression equation.

Electrical soil conductivity measurements at test location 358 were performed adjacent to (approximately 11 feet away) the SMI–PW–01 well cluster. Water quality results from ground water samples collected at discrete depth intervals from the SMI–PW–01 well cluster were previously reported in *Characterization of Groundwater Brine Zones at the Moab Project Site* (DOE 2002b). These previously reported water quality analyses (ammonia, chloride, density, specific conductance, sulfate, and TDS) provide a basis for comparison to the electrical soil conductivity results obtained at test location 358. Comparisons between soil conductivity and the previously reported ground water quality results are shown in the figures included in Attachment 9. Good agreement is obtained between the electrical soil conductivity results and specific conductance, density, TDS, ammonia, and chloride in ground water as indicated by the relatively high coefficient (r) values shown in the regression equations presented in Attachment 10. Conversely, a relatively poor linear correlation is obtained between soil conductivity and sulfate in ground water.

The electrical conductivity profile obtained at location 358 (Attachment 9) shows a sharp increase in soil conductivity at approximately 55 feet below ground level. At depths less than 55 feet, soil conductivity in the saturated zone ranges between approximately 400 and 500 mS/m. These relatively low soil conductivity values correspond with TDS concentrations that range between 10,000 and 20,000 milligrams per liter (mg/L) in ground water. At approximately 55 feet in depth, the soil conductivity increases from approximately 500 to over 1,000 mS/m. This increase in soil conductivity corresponds with an increase in TDS concentration that ranges from approximately 20,000 to 40,000 mg/L in ground water. The highest soil conductivity value (greater than 2,000 mS/m) is observed at a depth of approximately 80 feet and corresponds with the highest TDS concentration (approximately 80,000 mg/L) measured in ground water at location 358.

The pattern revealed by the sharp increase in conductivity at location 358 is similar to the conductivity profile observed for test location 364 at a depth of approximately 45 feet (see the 2,000 mS/m full-scale combined plots, Attachment 6). At a depth of 45 feet the conductivity increases sharply from approximately 300 to 1,000 mS/m, suggesting the presence of a contact between the upper fresh water (<10,000 mg/L TDS) and deeper more saline waters (>10,000 mg/L TDS). Water grab samples collected at depths of 40 and 54 feet (Attachment 7) indicate TDS concentrations of 7,910 and 19,220 mg/L, respectively, verifying the presence of the contact.

A pattern of increasing soil conductivity is also evident in the profile developed for test location 362 at a depth of approximately 30 feet, suggesting lower TDS concentrations in the ground water, although the magnitude of the increase in conductivity is not as pronounced as that observed for test locations 358 and 364 (see Attachment 6). Water grab samples collected at test location 362, from depths of 39 and 55 feet, indicate TDS values of 3,480 and 5,567 mg/L, respectively, verifying the presence of relatively low TDS concentrations (Attachment 7). Similarly, the soil conductivity profiles for the other test locations (borings 361, 363, 365, 366, 367, 368, and 369) suggest that relatively low TDS concentrations (<10,000 mg/L) are present in the ground water. Probe depths at these locations range from as shallow as 31.30 feet to a maximum of 75.75 feet. Ground water was not reached at location 360. Attempts to probe deeper were prevented by probe refusal in all cases.

Attachment 1

Description of the Conductivity Probe and Data Acquisition System

A PERCUSSION PROBING TOOL FOR THE DIRECT SENSING OF SOIL CONDUCTIVITY

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ABSTRACT

In recent years, percussion soil probing has become widely used for soil gas, soil core, and groundwater sampling. This paper describes a new tool for percussion probing that enables direct sensing of soil conductivity. The probe, which may be a cost effective alternative to borehole resistivity logging, can be readily deployed to detect lithology and contaminants at depths of 60 feet and more without the need for a borehole. Augmenting the versatility of the probe is a PC-based data acquisition system that produces a real-time display of the conductivity log and stores the data for further analysis.

The authors have found the system especially useful for characterizing site lithology. Specifically, the conductivity log reveals sand zones which can be subsequently targeted when setting screens for water sampling. Additionally, it distinguishes with excellent vertical resolution clay layers that may influence plume migration. Furthermore, since the log is displayed in real time and can be interpreted in the field, key information can be immediately substantiated by a discrete soil sample or a water sample using the same probing machinery.

Included in this paper is a description of the probe and its corresponding data acquisition system. The paper also explains field use of the probe and interpretation of the log it produces. Finally, examples of its use are presented to demonstrate how this new tool can be used to enhance site investigations.

INTRODUCTION

The purpose of this paper is to present techniques used and data gathered with soil conductivity probes driven into the ground using percussion soil probing equipment. This probe has been used to depths of up to 70 feet (21.3 m) and yields useful information for distinguishing various lithologic features. This paper presents a description of this soil conductivity probe, its construction, the related data acquisition system, sample soil conductivity logs, and an example of log interpretation.

The use of driven soil conductivity probes has several potential advantages for site investigators. Conductivity logs can be made through small diameter holes using light, mobile probing units. Multiple logs can be run in a single day. The technique does not require the pre-drilling of a bore hole for the logging operation and thus no cuttings are generated in collecting the information.

BACKGROUND

Recent years have seen an increasing role for the use of small diameter soil probing tools in subsurface investigations. These tools are typically 1 inch (2.5 cm) to 1.5 inches (3.8 cm) in diameter, are driven into the ground using percussion hammers, and are primarily used for sampling soil vapor, soil cores, or groundwater.

The increasing usage of these probing tools has been accompanied by improvements in tools and driving mechanisms which has gradually increased the depth of investigation at which probing tools are used. These factors have combined to create an increased demand for tools that will supply information concerning the lithology being penetrated by driven probes. Field operators have a constant demand to be able to distinguish sand zones from finer grained silt or clay zones by some method other than direct sampling.

The measurement of the electrical resistivity (the inverse of conductivity) has long been used as a logging tool in open boreholes both for water well and oil well applications. These resistivity logs can be extremely useful as an aid to the investigator in logging the lithology of the borehole. These logs increase in usefulness when used by investigators experienced in log interpretation, and familiar with the geology of the area of interest. Owing to their long history and variety of application, a wide variety of configurations of borehole logging tools has emerged. These tools vary with their diameter, contact spacing, number of contacts employed, and configuration of the current/voltage array.

Soil conductivity measurements and logs of soil conductivity profiles down to approximately 39 inches (1 m) have been used by agricultural scientists (Rhoades et al.,1976) for the purpose of determining soil salinity. Unlike borehole geophysical logging tools, the probes used in this application have direct contact with the soil.

More recently, soil resistivity measurements with depth have been made using cone penetration testing (CPT) equipment (Robertson et al.,1992). With these systems, relatively small diameter (1.4 inches to 2 inches outside diameter) tools are pushed into the ground using up to 20 tons of static weight at ground surface. Again, these tools employ resistivity measurement techniques similar to traditional borehole logging tools, but with the added advantage of direct contact between the soil and the probe and without the need for drilling of an open borehole as a conduit for the logging tool.

Unlike cone penetrometers which rely on static weight to advance tools into the ground, percussion probe units operate by applying an oscillating force or percussion to the top of the tool string being advanced into the ground. The effect of this percussion on soil conductivity measurements and tool life has heretofore been unknown.

The authors have undertaken to develop a probe for the measurements of soil conductivity with depth using a tool which is driven into the ground using a hydraulic hammer. The primary hurdles in the development of this tool concern the aggressive vibrations that a driven tool is subjected to. Prototype models of this probe experienced failures from vibration in contact rings, electrical conductors, and isolating materials. Each of these failure areas was analyzed and changes made in the design of the probe and materials of construction in order to extend probe life.

PROBE CONSTRUCTION

The sensing portion of the probe (Figure 1) consists of a steel shaft running through the center of four stainless steel contact rings. An engineering grade plastic electrically isolates the rings and the shaft from each other. This part of the probe is about eight inches (203.2 mm) long with a 1-inch (25.4 mm) diameter at the drive point and a 1-1/8-inch (28.6 mm) diameter just above the top ring. This geometry results in a one degree taper angle to assure soil contact with the rings as the probe is being pushed to depth. Above the sensing part of the probe is a two-foot (0.61 m) long steel shaft with a 1-inch

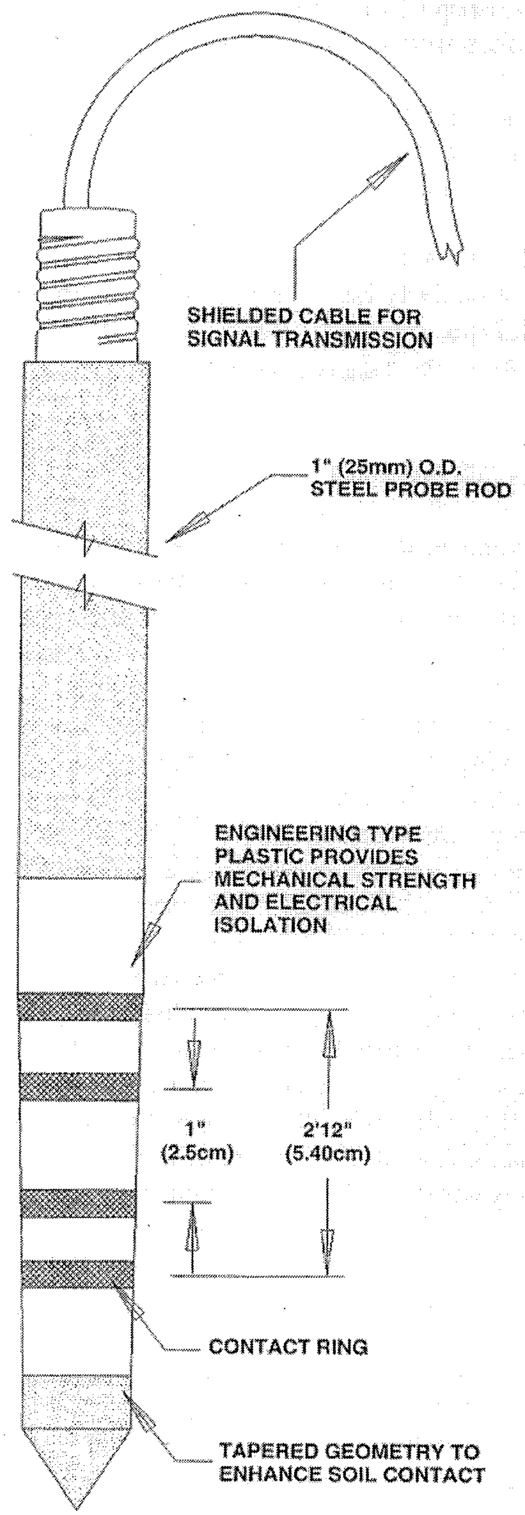

Figure 1. Conductivity Probe Construction

(25.4 mm) outside diameter and a 1/2 inch (12.3 mm) inside diameter. The shaft houses a shielded signal cable which is integrally connected to the probe via a watertight rubber seal.

Due to the high shock environment that the probe is subjected to, none of the electronics required for the system are built into the probe itself. Instead, the source for alternating current excitation of the probe and all signal conditioning circuitry (for voltage and current measurement) is housed in a separate ruggedized case. This construction philosophy also makes the probe less expensive to replace in case of failure in the field.

SYSTEM DESCRIPTION

A pictorial view of the conductivity system used in this work is shown in Figure 2. A probe approximately 1-1/8 inches (28.6 mm) in diameter with isolated contacts is advanced through the ground using a hydraulically driven percussion probing machine. Percussion is applied to the top of the probe rod at a rate of approximately 30 Hz and may result in instantaneous forces greater than 12,000 pounds being transmitted through the probe rods. Percussion also results in resonant vibrations which move along the probe rod between each blow. The probe is advanced to depth at a variable rate which depends on the strength of the soils being encountered and the cumulative friction on the probe rods. This rate typically varies from 2 to 25 feet per minute (0.6 to 7.6 meters per minute). Sections of probe rod are added as necessary to reach greater depth.
A signal cable attached to the probe is run through the inside diameter of the rod and then into

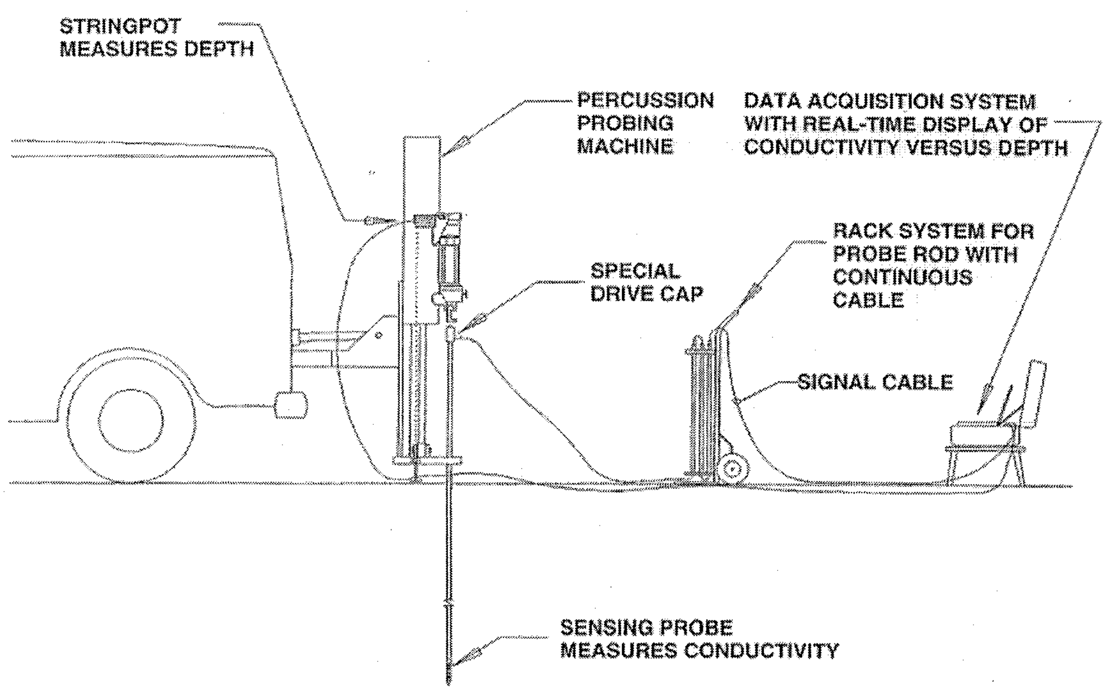

Figure 2. Major Components of the Conductivity Probe System

a PC-based data acquisition system housed in a ruggedized case. A specially designed probe rod cart allows the rods to be stored and handled with the cable strung through them.

Depth measurement is obtained from the stringpot system configured to measure the distance from the driving mechanism to ground surface. When driving the rod, a change in string length is indicative of the probes progression through the soil. The stringpot signal, which is proportional to the length of the string, is connected by a cable into the data acquisition system. The stringpot signal is used both to determine probe position and the speed at which the probe is moving.

A notebook PC, mounted in the case, provides a real-time display of conductivity versus depth during probing. In addition to the display, the data is stored in spreadsheet format for later analysis.

CONDUCTIVITY ARRAYS AND CALIBRATION

Two different conductivity arrays are presently being used (Figure 3), although more may be possible . The first is the Schlumberger array, which employs all four probe contacts, and the second is the dipole array, which uses just two.

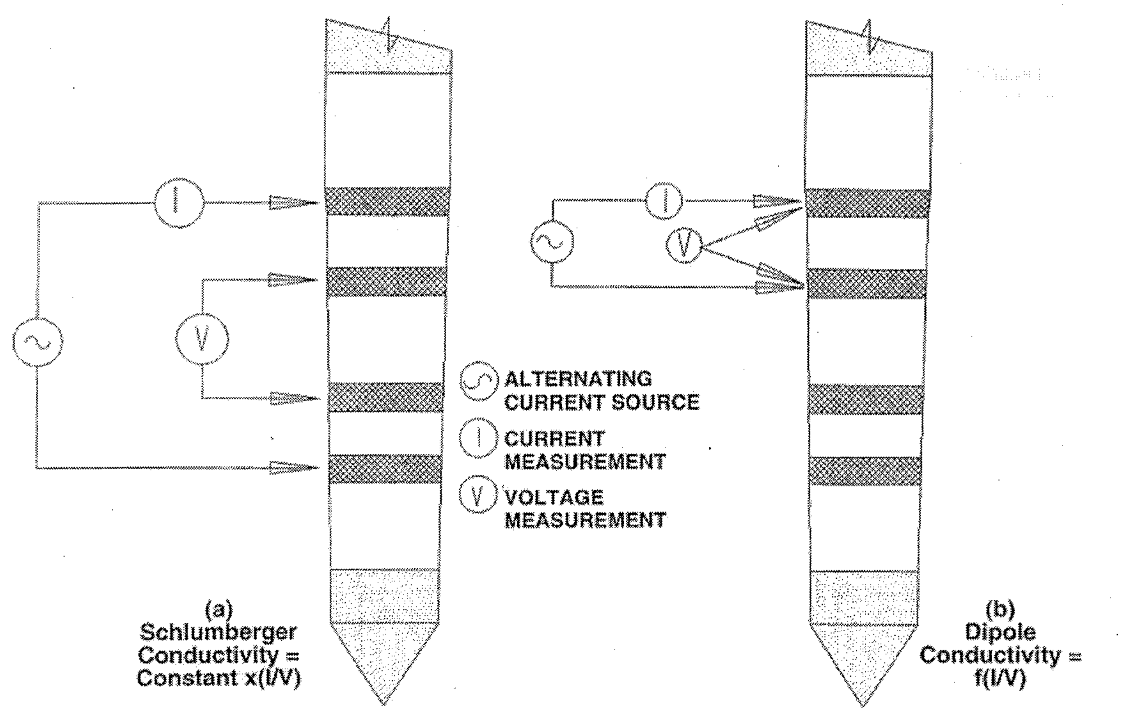

Figure 3. Electrode Arrays for Conductivity Measurements

In the Schlumberger array (Figure 3a), current is sent through the formation between the top and bottom contacts of the probe. This current is measured along with the voltage that results across the middle two contacts. The conductivity is merely a constant times the ratio of current to voltage. This array is effective even when soil contact with the probe is not ideal. Specifically, if poor contact causes less current to flow between the top and bottom contacts, the voltage drop across the inside contacts would also decrease. The Schlumberger array is identical to the widely used Wenner array except that the Wenner array has all four contacts evenly spaced.

Figure 4 shows the response of the Schlumberger array to being immersed in liquids of known conductivity. In accordance with theory, the response is basically linear, especially up to 400 mS/m, which is higher than the soil conductivities encountered in this work. Linear regression was applied to the data shown to determine the calibration constant for this probe.

Although the Schlumberger array yields good vertical resolution, it may be desirable to increase resolution for some applications. This could be done by constructing a probe with less spacing between the four contacts. Alternatively, it may be more practical to use the same probe connected in a dipole array. The dipole, shown in Figure 3b, uses just two contacts of the probe by passing current from one contact to the other through the formation and measuring the voltage across the same two contacts. Such an array would not be considered feasible for surface resistivity measurements (Milsom, 1987) because poor contact with the soil would produce an artificially high resistivity. However, much better contact is obtained during soil probing, making the dipole a viable option. The dipole has the added benefit of allowing alternate uses of the remaining contacts on the probe.

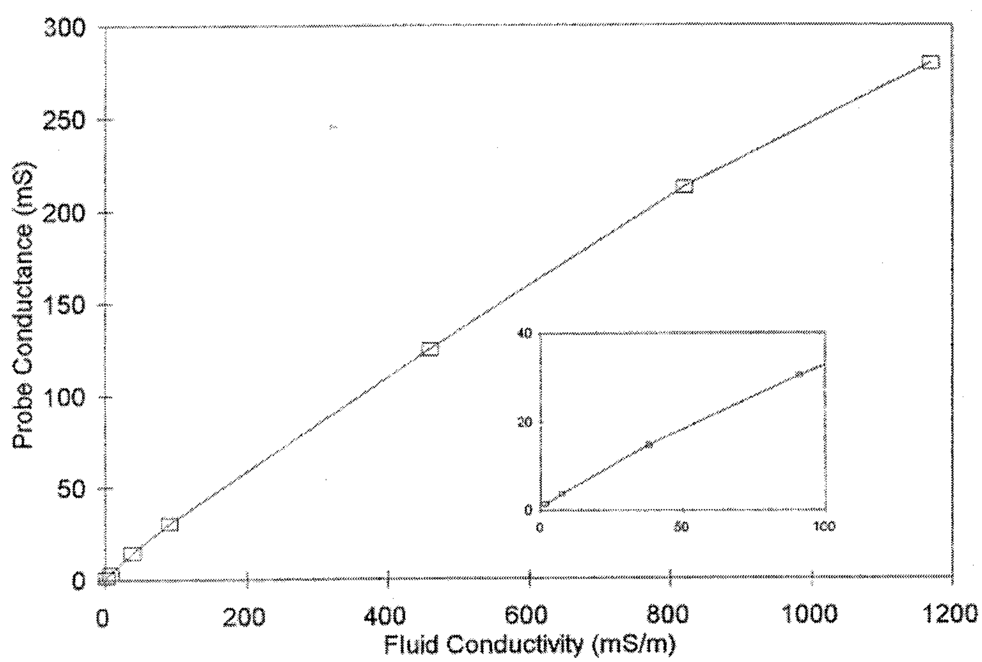

Figure 4. Schlumberger Array Calibration

Unlike the Schlumberger array, the dipole does not react linearly to variations in formation conductivity. Figure 5 shows the conductance sensed by three different dipole spacings for a variety of liquid conductivities. The nonlinear response can be accommodated by using a second order equation to calibrate the probe instead of the linear calibration used for the Schlumberger array. Figure 6 shows the curve fit used for the short dipole, which was formed using the top two rings of the probe. The fit is almost exact up to 400 mS/m, making it adequate for the range of conductivities encountered at the test location.

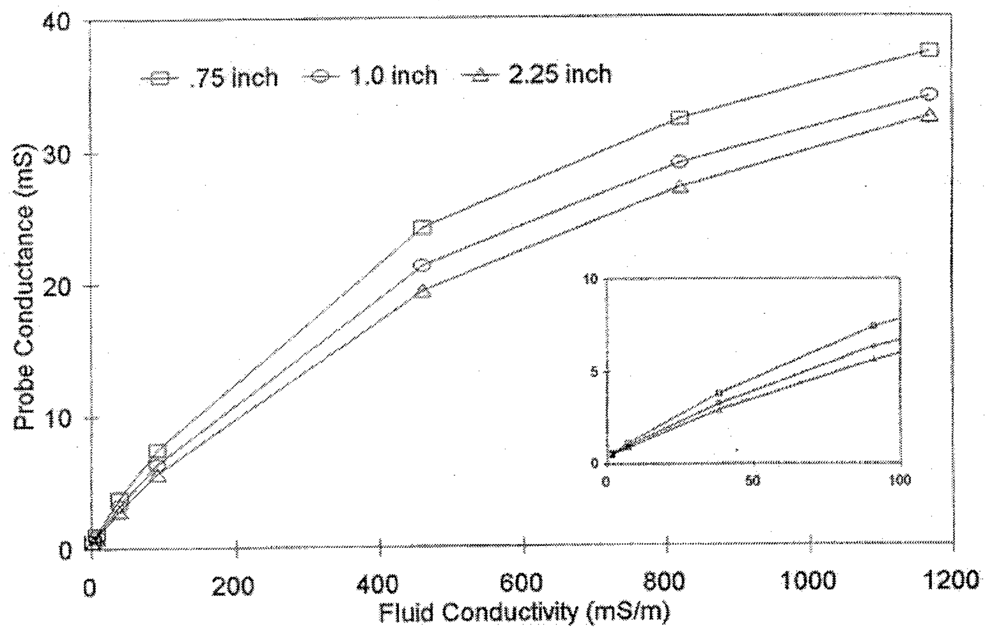

Figure 5. Dipole Array Calibration

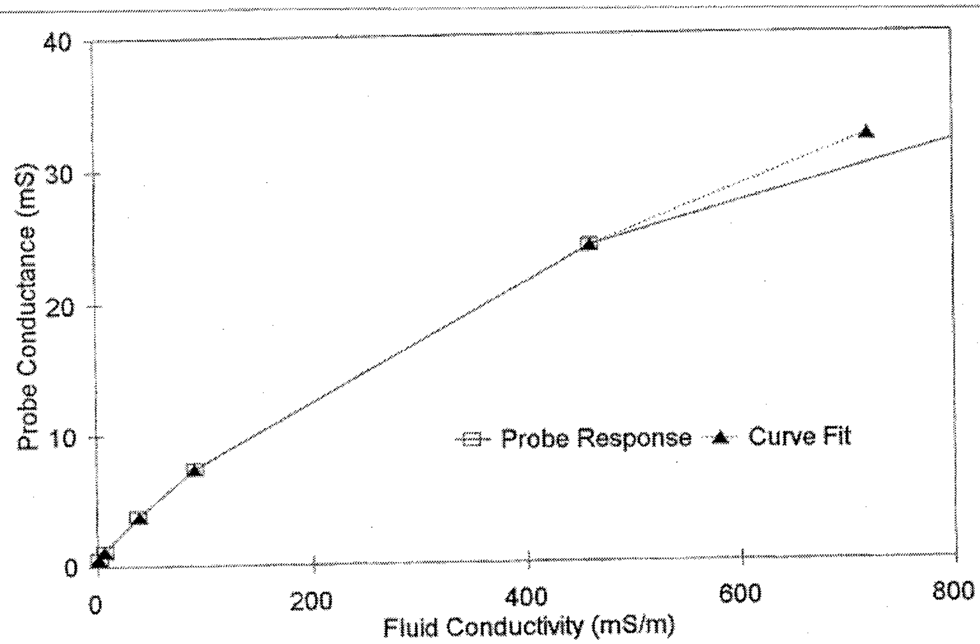

Figure 6. Curve Fit for Dipole Array Calibration

FIELD REPEATABILITY

Besides being able to calibrate a conductivity probe, the field investigator is also interested in the repeatability of the tool when applied in the field. This question goes beyond the ability of the probe to maintain its calibration when repeatedly placed in a claibration tank of known conductivity fluid. The field investigator must have assurance of the consistency of the soil in its electrical response to the probe and the ability of the probe to make repeatable measurement while undergoing percussion at 30 Hz (which results in thousands of G's of acceleration at the probe tip). The conductivity probe technique must be repeatable to be of value for site investigation.

Unfortunately, no test is possible to measure the repeatability of a probe in a natural soil; the probe being a tool which causes disturbance as it makes measurements. Duplicate measurements through the exact same path through the same undisturbed soil are impossible. However, a useful concept of the working repeatability of the probe can be attained by making successive probings at locations offset by short increments. Figure 7 shows the results from three successive probings, each probe being placed approximately 1 foot (0.3 m) from the other two. These logs were made using the probe in the previously described Schlumberger configuration. It should be noted that due to soil heterogeneity, there is no certainty that the three probes were sampling the same material, despite their close proximity. The figure does indicate that the major features of the soil profile which determine electrical conductivity are consistent at this location and can be repeatably measured with the probe.

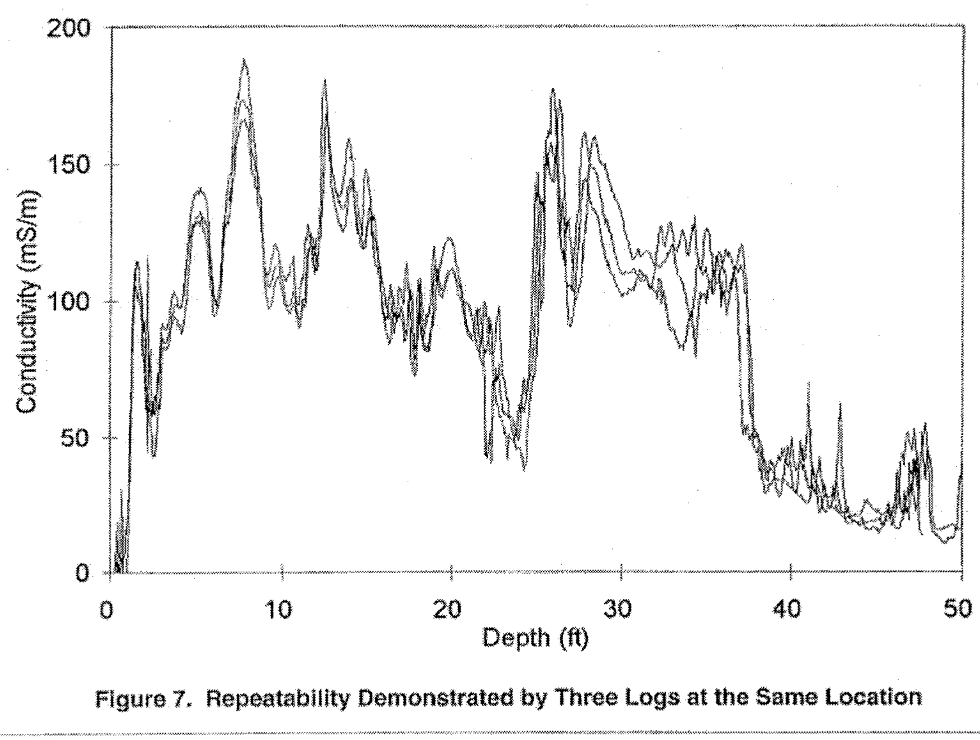

Figure 7. Repeatability Demonstrated by Three Logs at the Same Location

CONDUCTIVITY LOG INTERPRETATION

One of the first points to state concerning interpretation of electrical logs generated with driven probes is that it is not critical whether the soil electrical property is expressed as a conductivity or as the inverse, resistivity. All of the data is stored in digitized spreadsheet format and the field investigator can invert the output to yield the desired unit of expression. As referenced earlier, agricultural soil scientists have traditionally worked with units of soil conductivity, while geologists and geophysicists have used units of resistivity. All of the logs discussed here will be shown in units of conductivity.

There are many factors which will affect the measurement of soil conductivity. Most investigators cite first and foremost the degree of saturation and the conductivity of the saturating fluid. Other factors are also important, such as the clay content of the soil, soil structure, the ability of the soil to make mechanical contact with the probe, and the presence of contaminants in the soil.

Figure 8 shows a log of soil conductivity made to a depth of 62 feet (18.9 m) in an alluvial valley area in central Kansas. This log was made using the probe in the Schlumberger electrode configuration. At a close offset to this probing hole, approximately 3 feet (1 m) away, a continuous core sampling was made of the soil strata. Twenty-nine samples from this core hole were recovered, logged in the field, and then submitted for grain size analysis. A log of the percent finer than a No. 200 mesh U.S. standard sieve (0.074 mm opening) from each soil sample is presented in Figure 8 along with the soil conductivity profile and the sample description log. The water table was measured in the open core hole at a depth of approximately 22 feet (7.7 m) below ground surface. Groundwater was sampled at this location from a depth of 45 feet (15.7 m) and was found to have a conductivity of 83 mS/m. The alluvium consists of mixed clays and silts to a depth of approximately 40 feet (12.2 m), followed by mixed sands to a depth of 60 feet (18.3 m), where shale is encountered at the base of the valley.

As can be seen from Figure 8, the conductivity log does a good job of detecting the presence of clean sands at the 42 to 60 feet (12.8 to 18.3 m)depth, including the transition from clay to sands in the 38 to 42 feet (11.6 to 12.8 m) depth. Intermittent clay lenses are clearly seen at the 47.5 foot (14.5 m) depth and again at the 51 foot (15.5 m) depth. Shale at the base of the hole is seen with an increase in conductivity. The mixed, predominantly clay and silt strata in the upper part of the alluvium is shown with higher conductivity values. The conductivity log correctly shows the sand zone at 25 feet (7.6 m) and a silt zone is shown on the sample log at 10 feet (3.0 m).

Conductivity logs made with driven probes are similar to borehole resistivity logs in that they do not provide unique identification of soil strata. The investigator must calibrate the log at the site by logging at a location where a sample log is available. The true utility of conductivity logs made using probing tools is to extend the investigators information horizontally from known vertical profiles. An example of this can be seen in Figure 9 where the alluvial soil strata previously described in Figure 8 is traced horizontally across a site with subsequent logs. Of importance in these logs is the consistency of the soil conductivity profile across the site. Using these logs, it is a simple task to correlate the upper silts and clays in the cross section. The shale increases

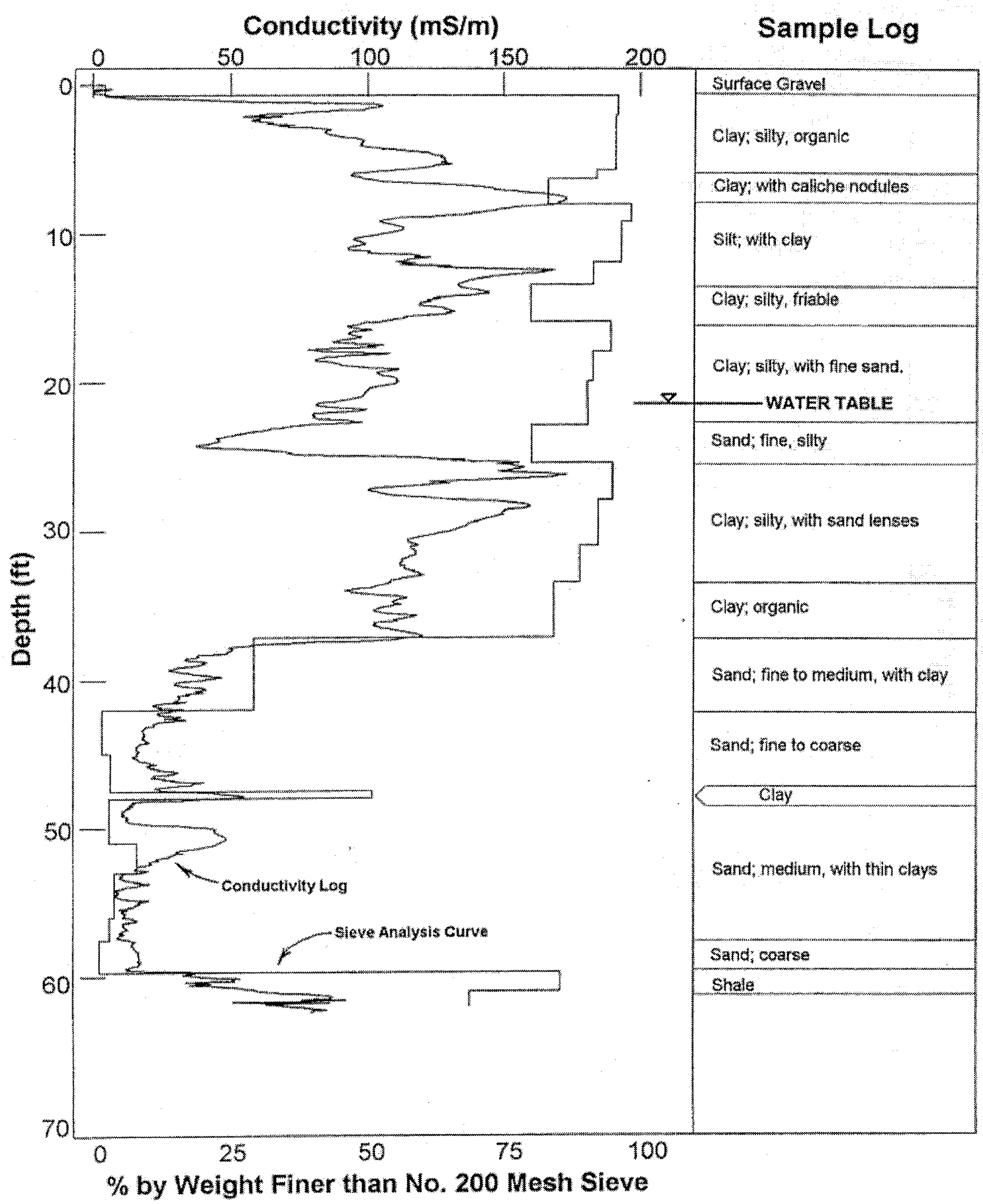

Figure 8. Compilation of Soil Conductivity, Minus 200 Mesh Fraction. and Sample Log Location: KEI - B

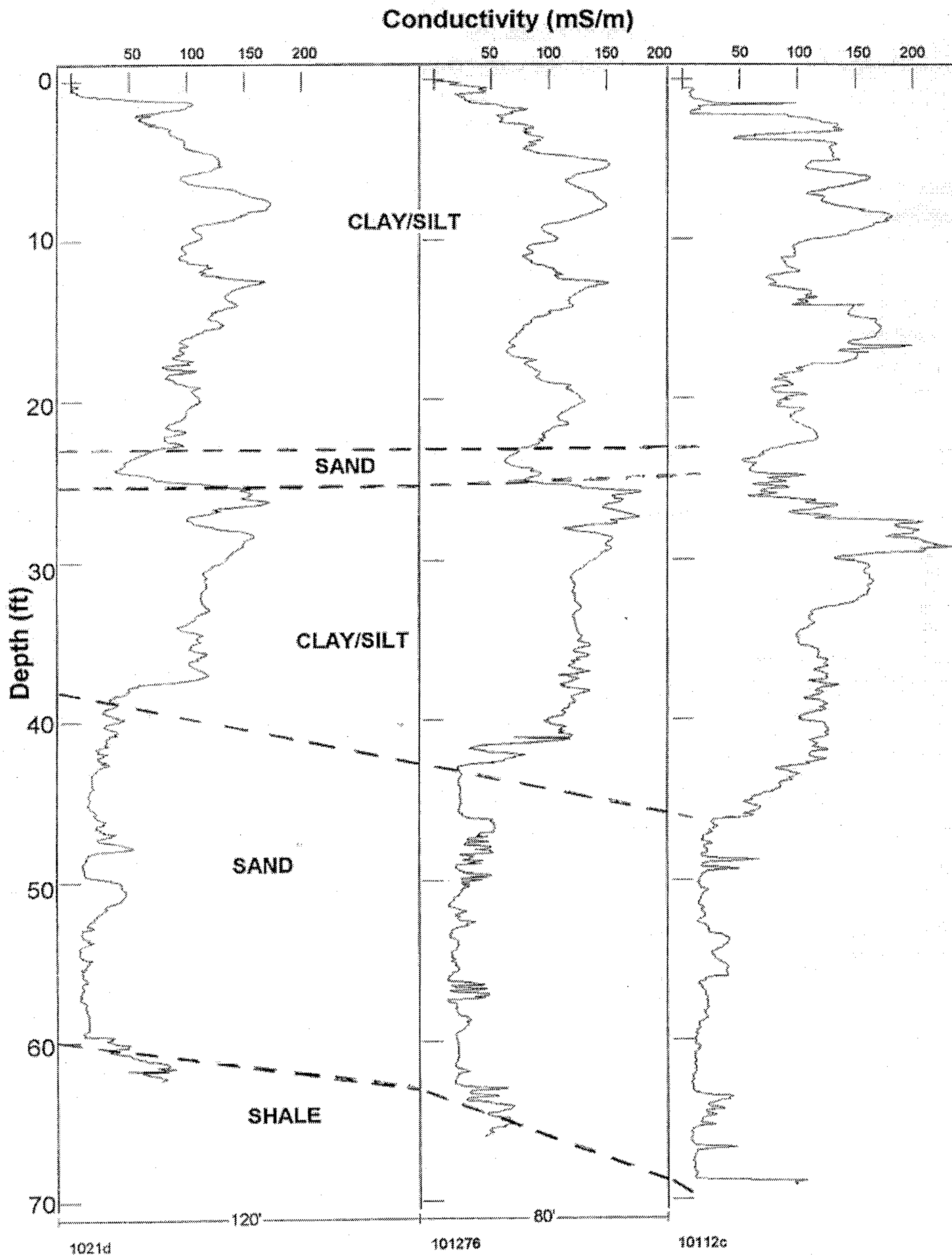

Figure 9. Conductivity Logs Spaced Horizontally Across the Site

gradually in depth moving left to right. Anomalies to this pattern can be expected to represent either changes in the soil profile or the presence of contaminants.

INCREASED VERTICAL RESOLUTION USING THE DIPOLE ARRAY

Figure 10 shows the response of the dipole array and the Schlumberger array at approximately the same location (the probe holes are within three feet of each other). The response of the two arrays are basically the same, substantiating the feasibility of the dipole. In addition, the more detailed imaging of the dipole can be seen by looking at an exploded view like that shown in Figure 11. The figure shows a close up of the clay strips embedded in the sands from 46 to 52 feet (14.0 to 15.9 m). In three cases shown on this interval, the dipole array shows two distinct strips where the Schlumberger shows just one.

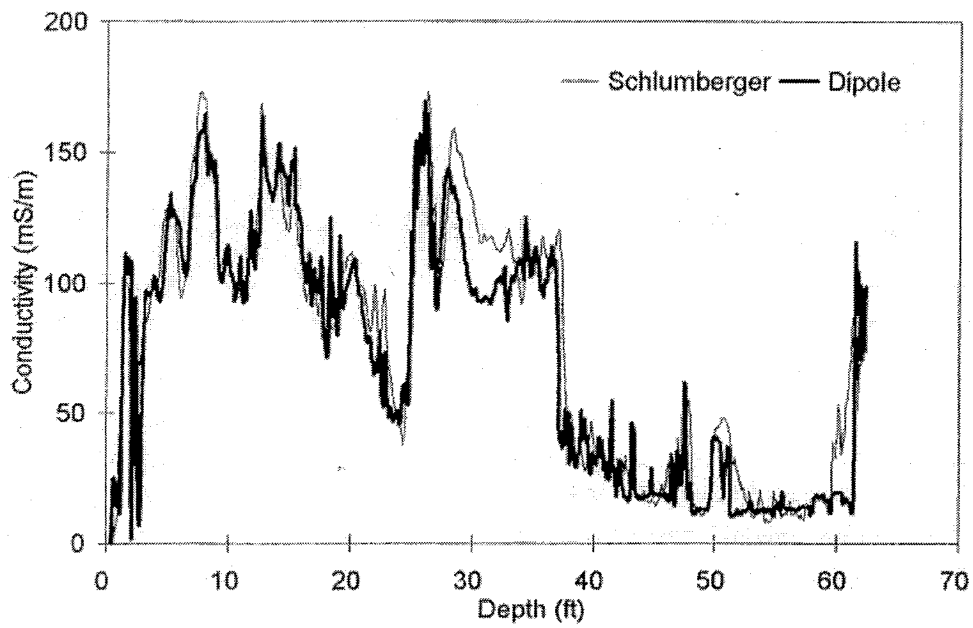

Figure 10. Dipole and Schlumberger Arrays Used at the Same Location

The dipole's vertical resolution could be further increased by decreasing the spacing between the two contacts. However, it should be pointed out that the increase in vertical resolution that results will also decrease depth of investigation. As a result, a dipole formed by very narrowly spaced contacts may not sense beyond the material compacted by the probe. Such compaction could alter

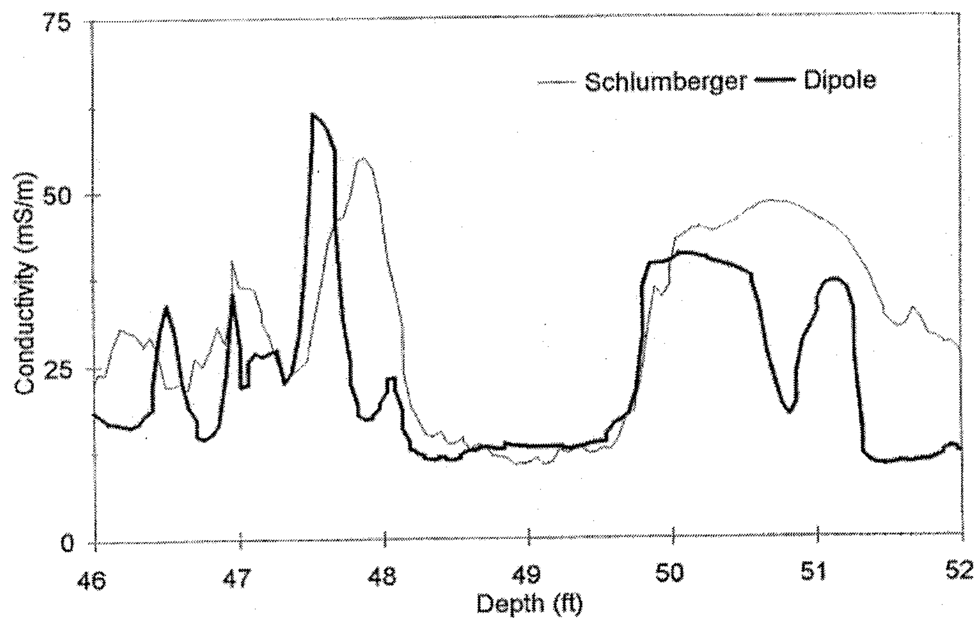

Figure 11. Example of Increased Vertical Resolution Using the Dipole Array

the conductivity of the soil thereby limiting accuracy. This dilemma could be overcome by applying both array types at a given site.

CONCLUSIONS

This work has demonstrated the basic functionality and repeatability of a percussion probing tool for the direct sensing of soil conductivity. The comparison with a sample log and sieve analysis substantiated the ability of the probe to provide useful lithologic information to the site investigator. Furthermore, logs across the test site were presented to show how the probe can be used to determine variations in strata over a broad area. Comparisons between the Schlumberger and the dipole array showed a general agreement in response with the dipole providing more resolution. Due to the trade-off between vertical resolution and depth of investigation, both arrays would probably be used in a given investigation.

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BIOGRAPHICAL SKETCHES

Colin D. Christy, P.E.
Mr. Christy earned the B.S. in Electrical Engineering from the University of Missouri-Rolla in 1987 and the M.S.E.E. degree from Iowa State University in 1990. He has worked with Geoprobe Systems since March of 1993 and is currently involved in the research and development of direct sensing probes. Mr. Christy is a Registered Professional Engineer in the State of Illinois.

Thomas M. Christy, P.E.
Mr. Christy earned his B.S. in Civil Engineering from the University of Missouri-Rolla in 1980. Upon graduation, he worked as a consultant performing numerous site characterization studies for industrial clients. In 1987, Mr. Christy co-founded Geoprobe Systems, a manufacturer of percussion soil probing equipment. He is vice-president of the company and works with marketing and research and development.

Volker Wittig
Mr. Wittig earned his Diploma in Mechanical Engineering at the University of Carolo Wilhelmina in Braunschweig, West Germany. He received his M.S. in Agricultural Engineering at South Dakota State University in 1990. He has worked with Geoprobe Systems since 1992 on the development of soil probing tools. Mr. Wittig is a member of the ASTM Committee for Vadose Zone Monitoring and Ground Water Sample Collection and Handling.

Attachment 2

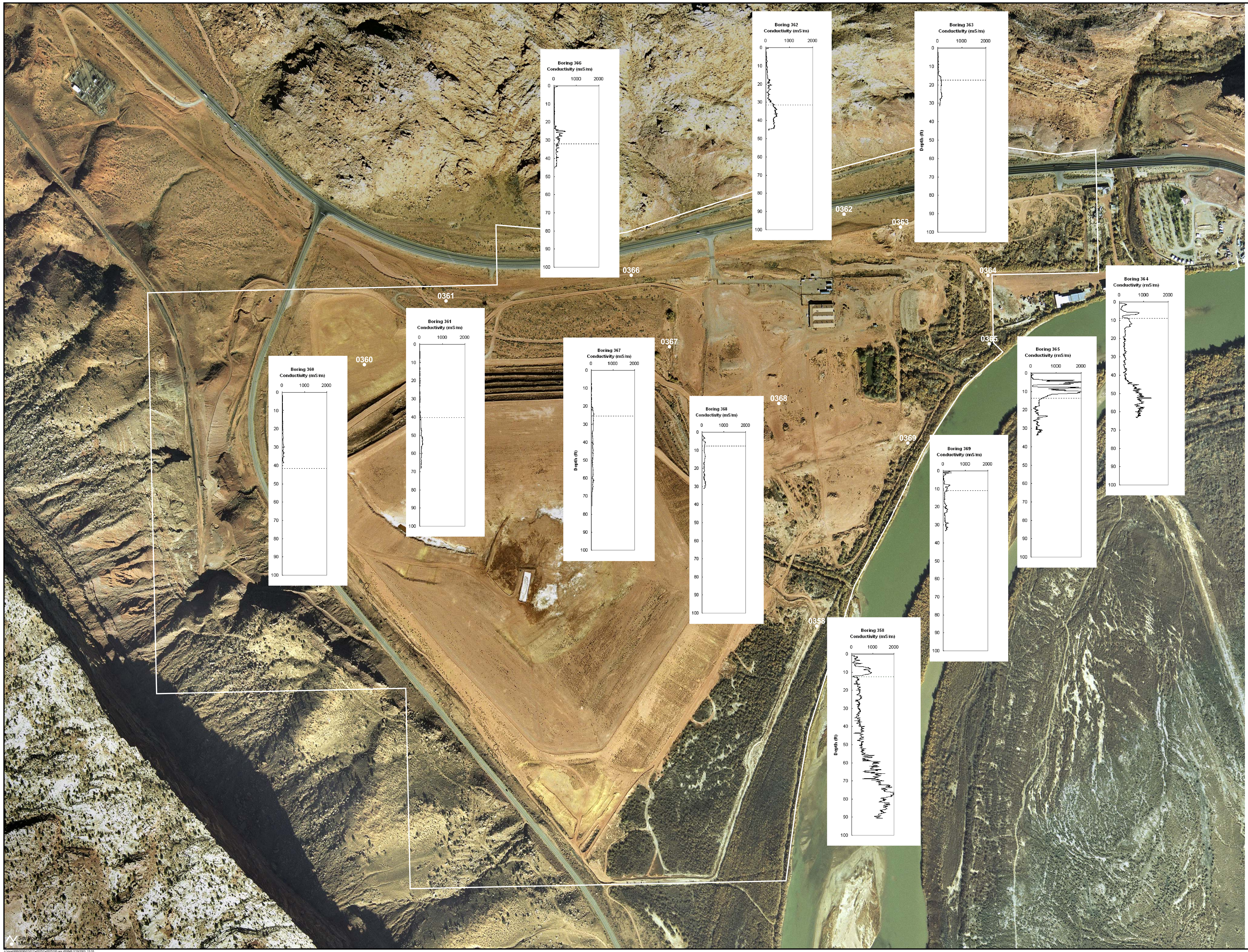
Photographs of the Marl (M5T) Rhino Rig (ConeTec, Inc.)


ZIEMAN
2320
06/19/2002


D & A
06/21/2002

Attachment 3

Soil Conductivity Measurement Locations



Site Boundary
Measurement Location

N

300 0 300 Feet

U.S. DEPARTMENT OF ENERGY GRAND JUNCTION OFFICE GRAND JUNCTION, COLORADO	Prepared by S.M. Stoller Corporation Under DOE Contract No. DE-AC13-02GJ79491
Location Map	
Soil Conductivity Measurement Locations	
DATE PREPARED: February 19, 2003	FILENAME: X0025100-01

Attachment 4

Coordinate Location Table

(**Note:** Coordinates are Modified Utah State Plane, Central Zone, North American Datum [NAD] 1983/1994. Elevations are North American Vertical Datum [NAVD] 1988.)
FT BLS = feet below land surface

BOREHOLE REPORT (USEE310) FOR SITE MOA01, MOAB
REPORT DATE: 10/31/2002 7:53 am

LOCATION CODE	NORTH COORD. (FT STATE-PLANE)	EAST COORD. (FT STATE-PLANE)	GROUND ELEV. (FT)	BORE HOLE DEPTH (FT BLS)	BORE HOLE DIA. (INCHES)	DATE ESTAB.	INSTALLED BY	LOCATION SUBTYPE	LOCATION COMMENTS
0358	6664481.42	2186198.80	3966.60	90.60	1.1	06/21/2002	MACTEC-ERS		Soil Conductivity Measurement
0360	6666201.45	2183222.86	4001.10	38.70	1.1	07/11/2002	MACTEC-ERS		Soil Conductivity Measurement
0361	6666620.25	2183760.00	3999.80	68.40	1.1	07/11/2002	MACTEC-ERS		Soil Conductivity Measurement
0362	6667191.30	2186378.16	3987.70	55.00	1.1	07/13/2002	MACTEC-ERS		Soil Conductivity Measurement depth to 45.45'; water sampling depth to 55'
0363	6667106.45	2186749.39	3973.30	31.60	1.1	07/12/2002	MACTEC-ERS		Soil Conductivity Measurement
0364	6666788.85	2187325.58	3963.90	63.25	1.1	07/11/2002	MACTEC-ERS		Soil Conductivity Measurement
0365	6666339.04	2187332.92	3967.60	33.75	1.1	07/12/2002	MACTEC-ERS		Soil Conductivity Measurement
0366	6666789.63	2184978.17	3989.90	45.55	1.1	07/13/2002	MACTEC-ERS		Soil Conductivity Measurement
0367	6666319.54	2185228.77	3982.50	75.75	1.1	07/09/2002	MACTEC-ERS		Soil Conductivity Measurement
0368	6665946.13	2185949.69	3963.50	31.30	1.1	07/11/2002	MACTEC-ERS		Soil Conductivity Measurement
0369	6665685.82	2186797.89	3964.90	33.45	1.1	07/13/2002	MACTEC-ERS		Soil Conductivity Measurement

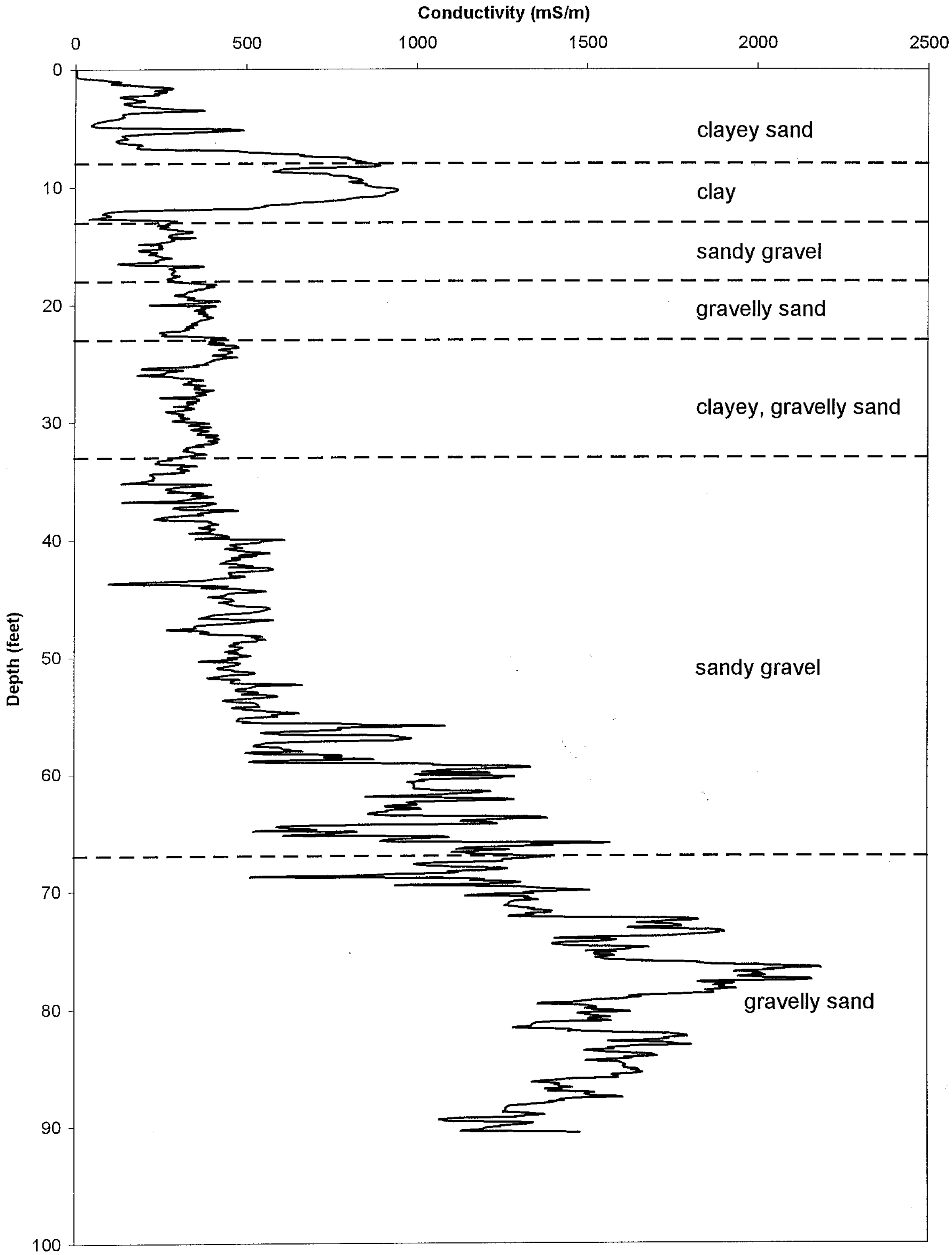
RECORDS: SELECTED FROM USEE310 WHERE site_code='MOA01' AND location_code in('0362','0364','0358','0360','0361','0363','0365','0366','0367','0368','0369')

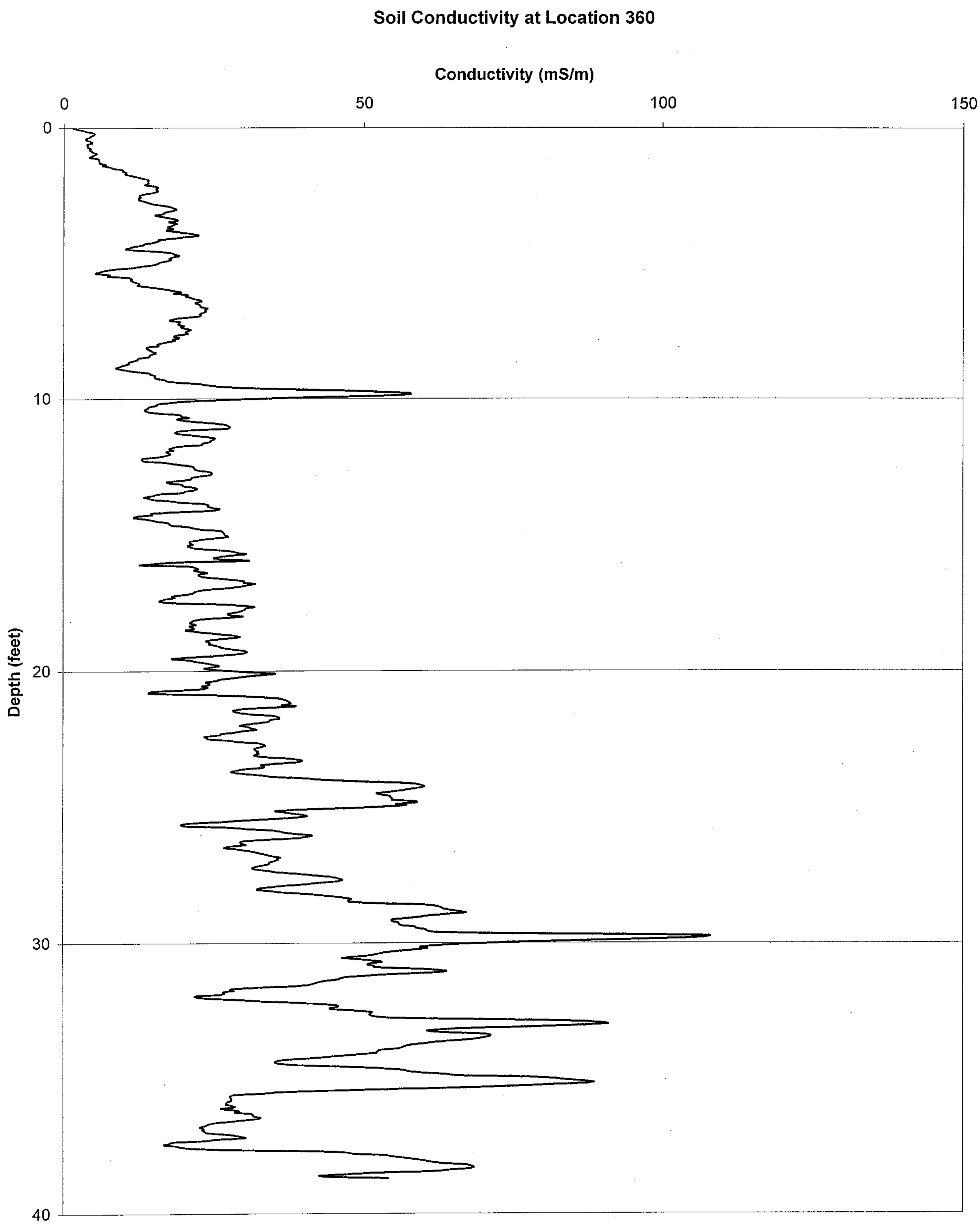
LOCATION SUBTYPES:

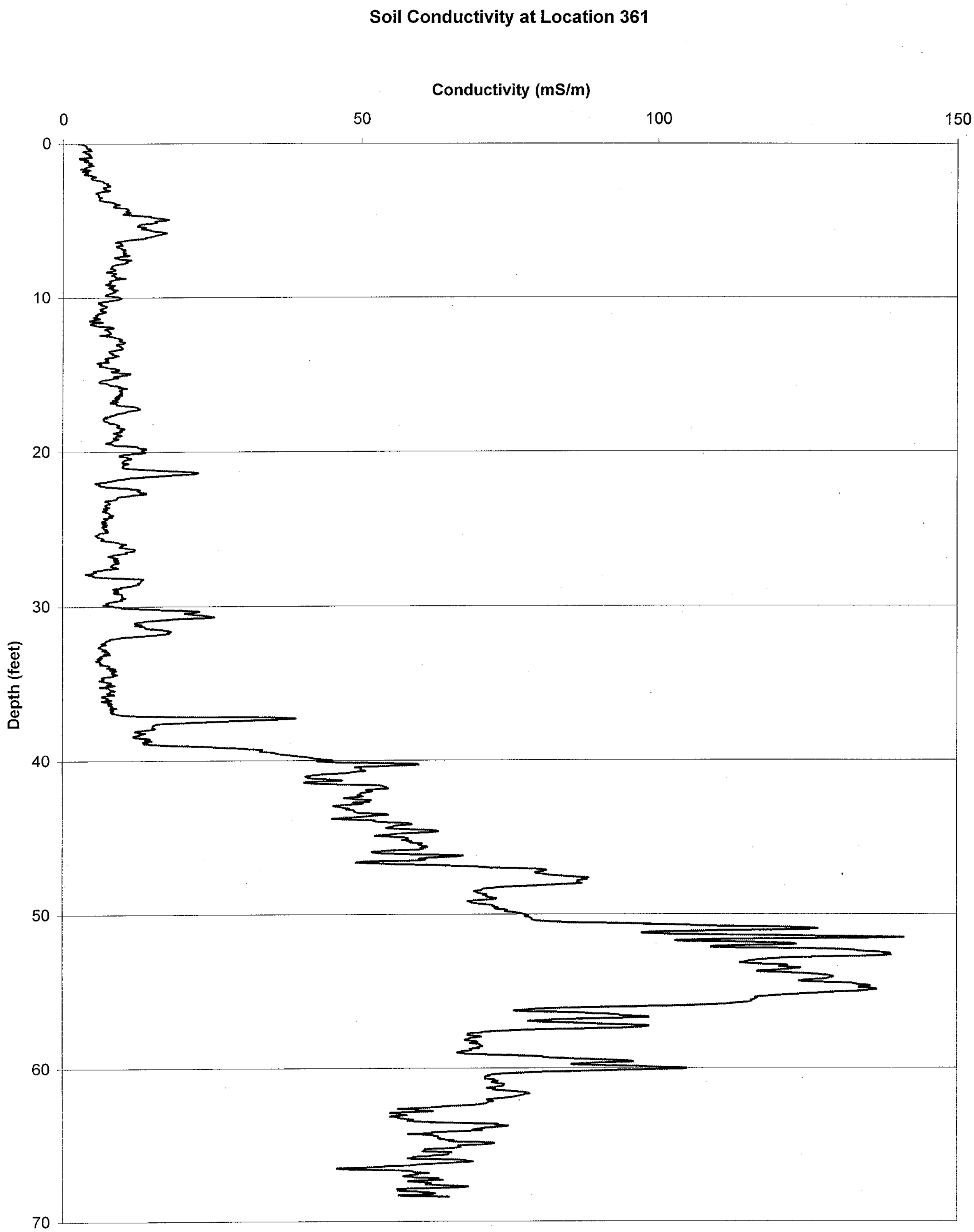
Attachment 5

Individual Soil Conductivity Profiles

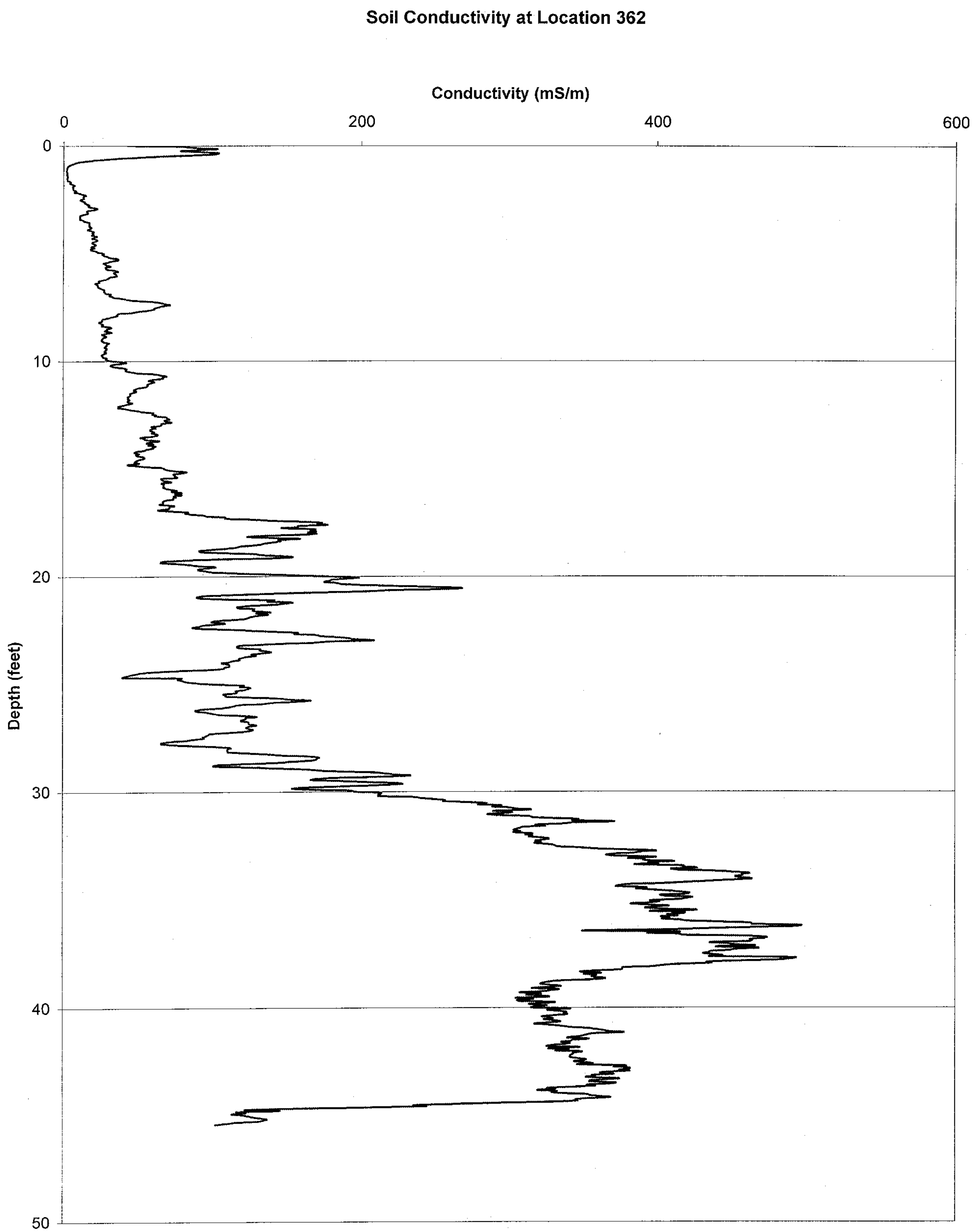
Soil Conductivity at Location 358

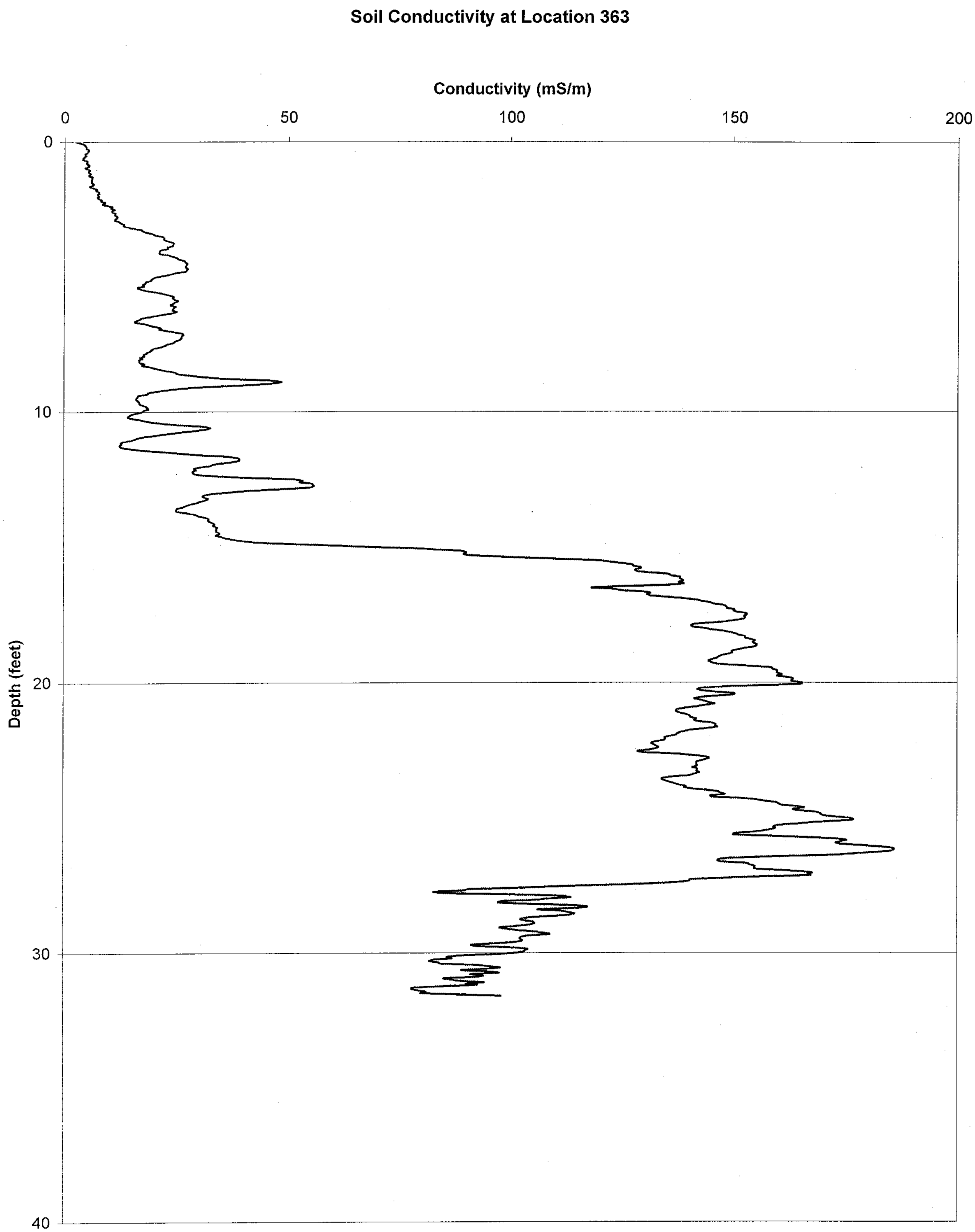


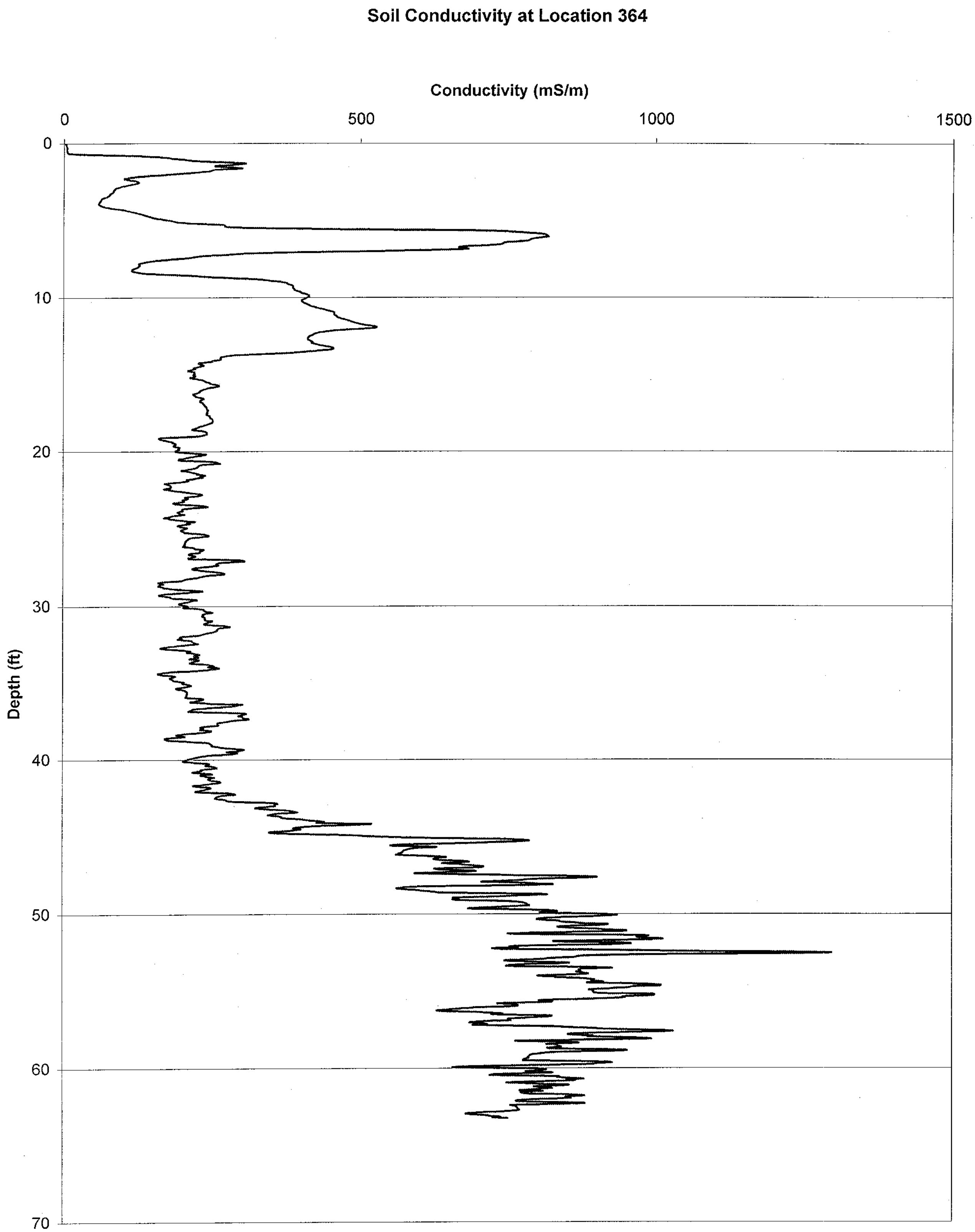

Soil Conductivity at Location 360
Conductivity (mS/m)
0
50
100
150
Depth (feet)
0
10
20
30
40



Soil Conductivity at Location 361
Conductivity (mS/m)
0
50
100
150
Depth (feet)
0
10
20
30
40
50
60
70

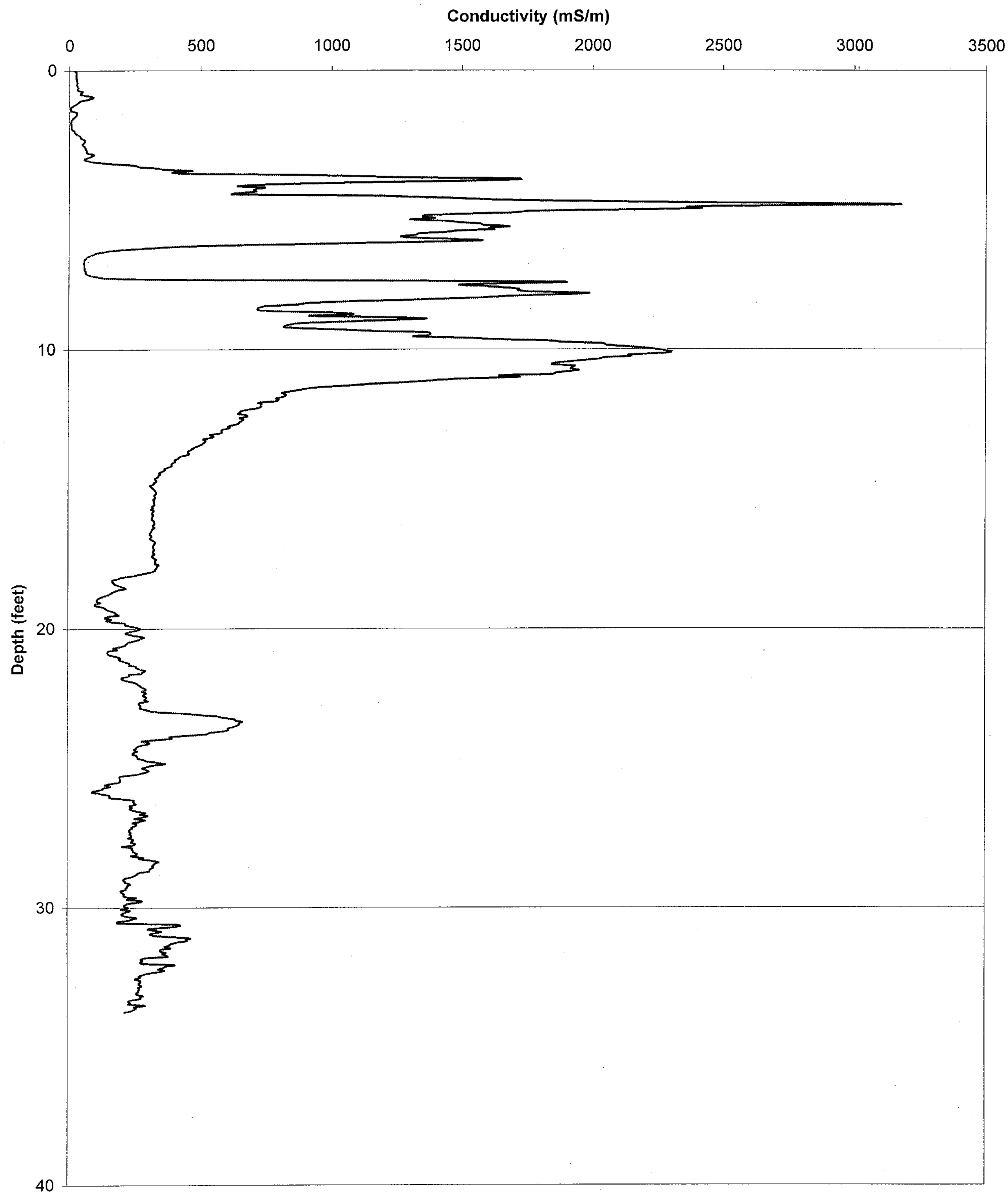

Soil Conductivity at Location 362
Conductivity (mS/m)
0
200
400
600
Depth (feet)
0
10
20
30
40
50


Soil Conductivity at Location 363
Conductivity (mS/m)
0
50
100
150
200
Depth (feet)
0
10
20
30
40

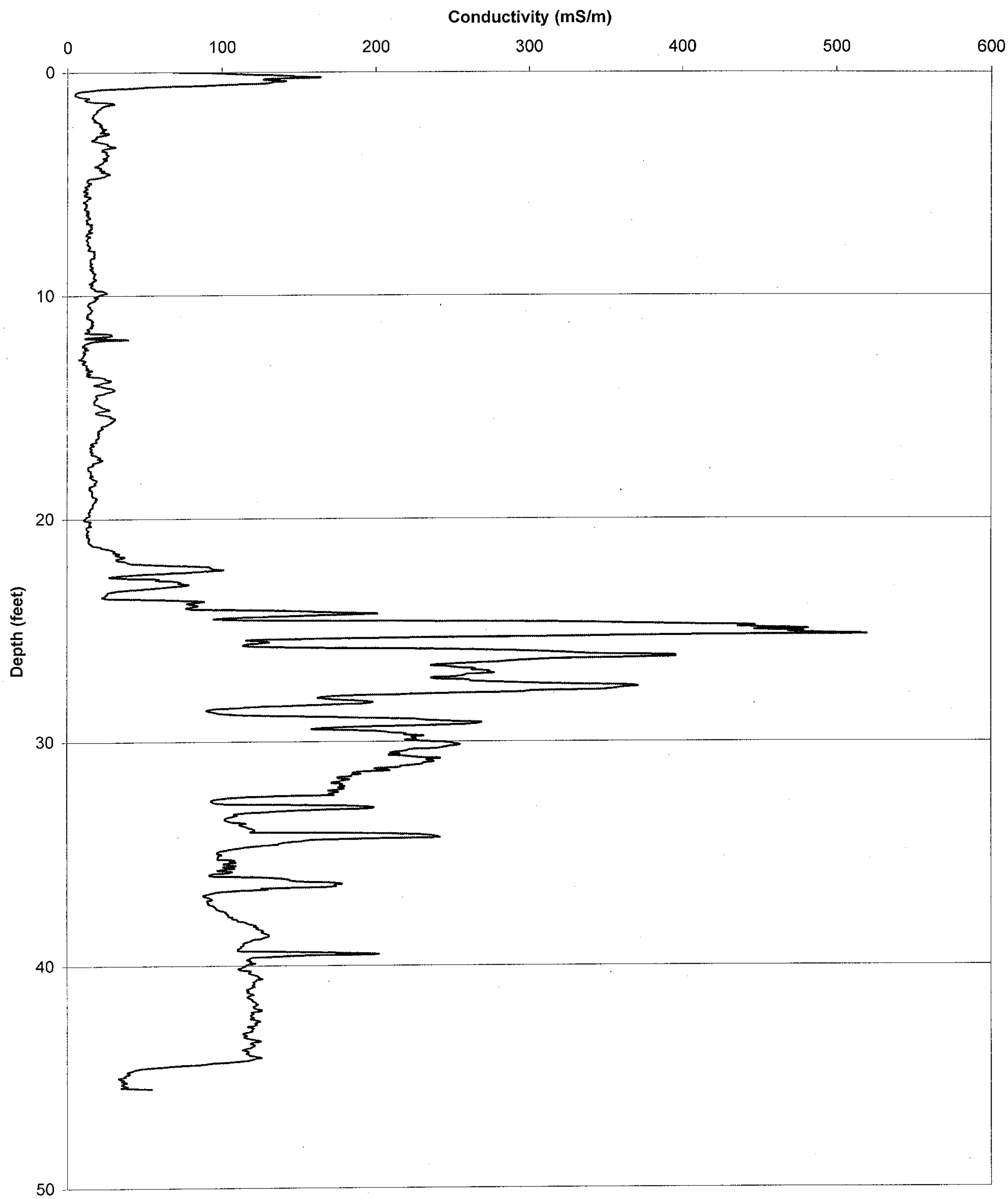


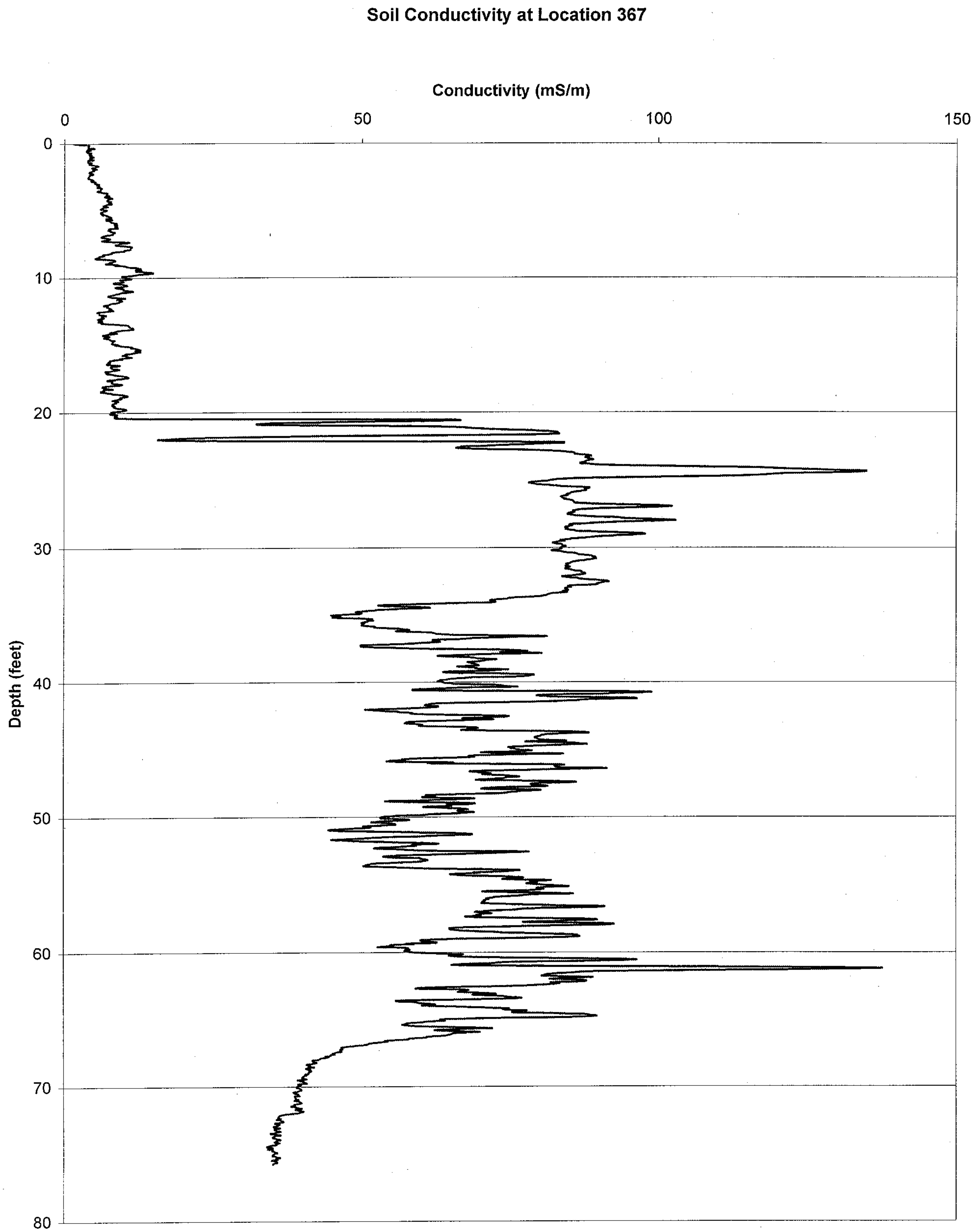
Soil Conductivity at Location 364
Conductivity (mS/m)
0
500
1000
1500
Depth (ft)
0
10
20
30
40
50
60
70

Soil Conductivity at Location 365

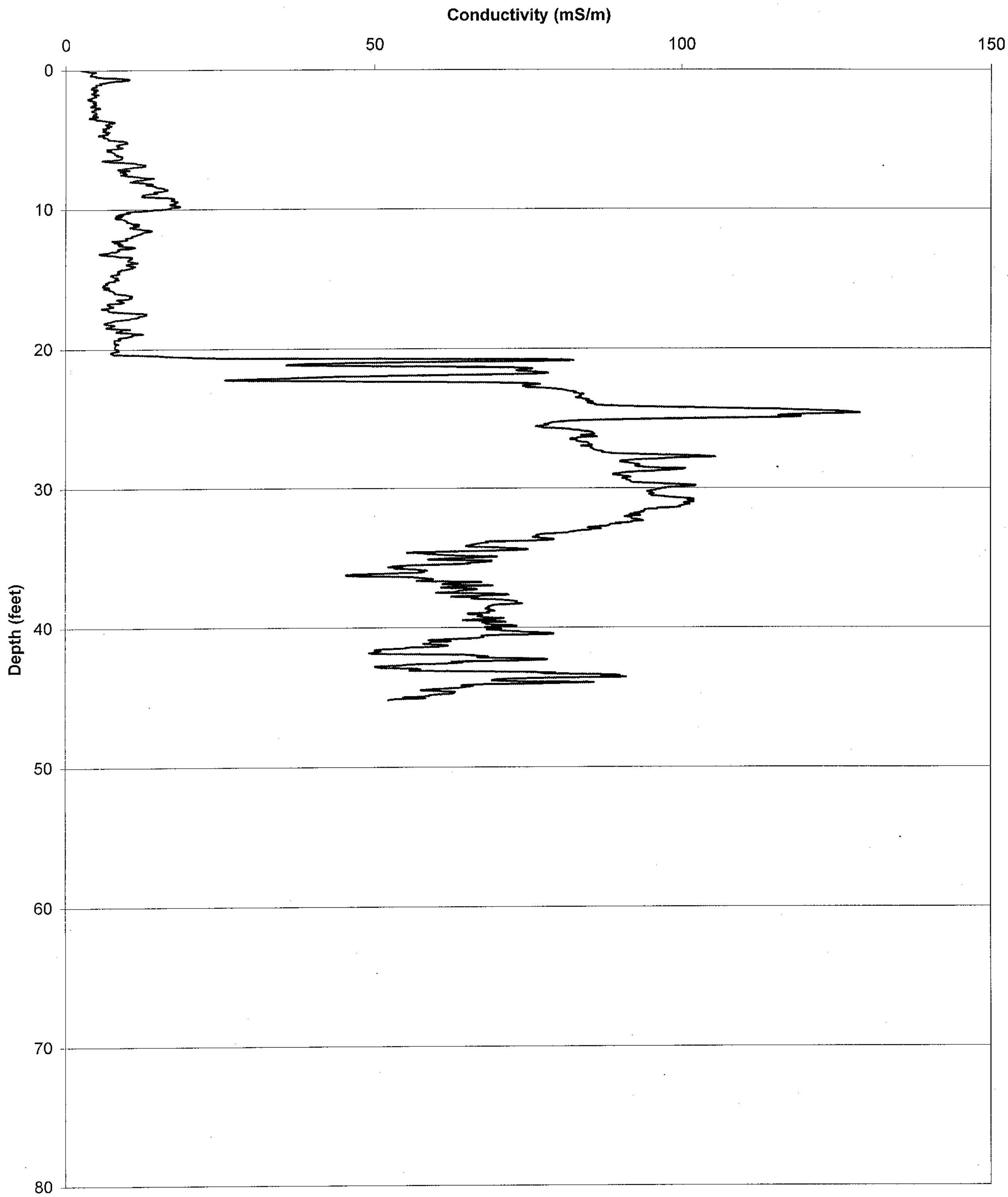


Soil Conductivity at Location 366

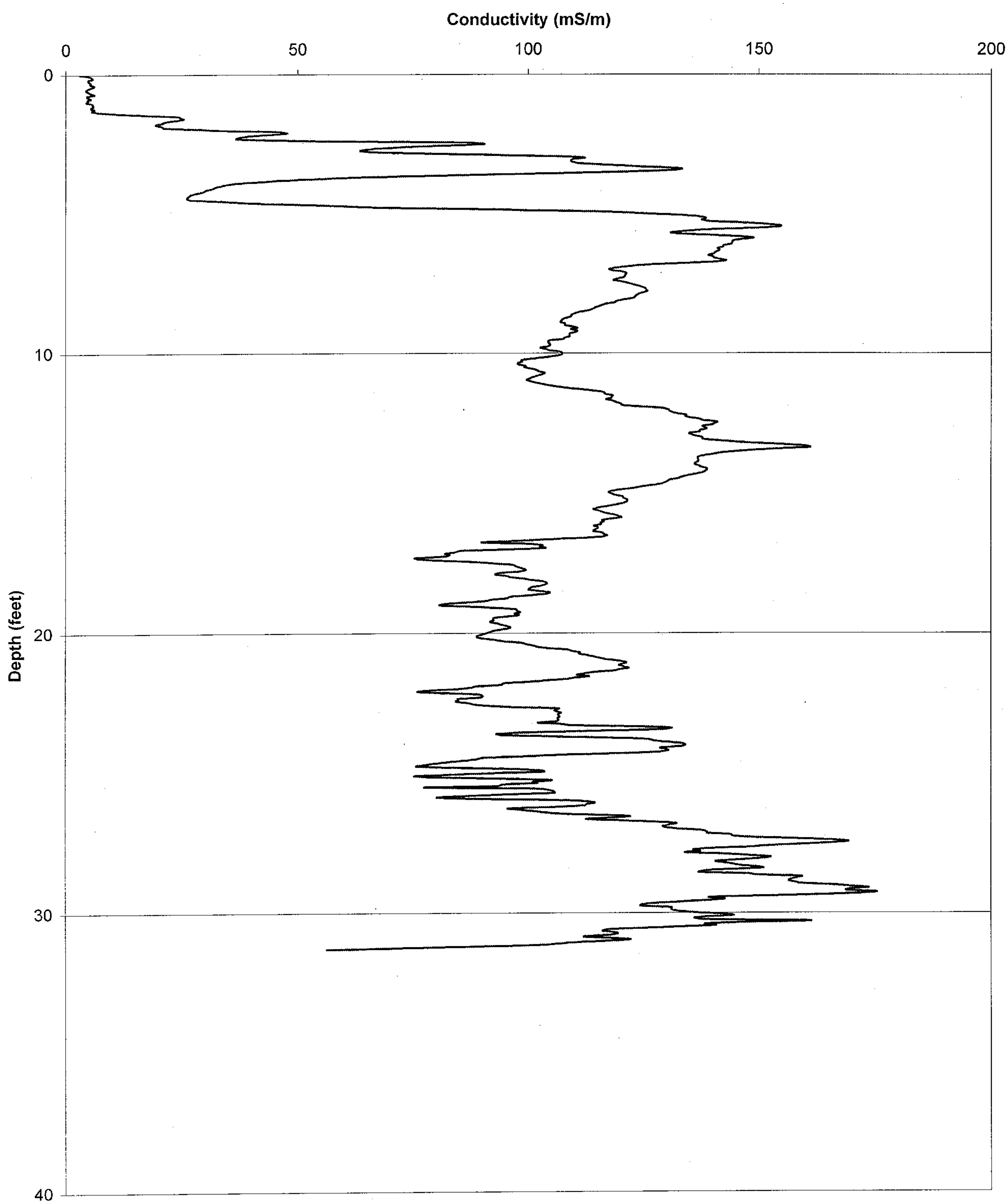



Soil Conductivity at Location 367
Conductivity (mS/m)
0
50
100
150
Depth (feet)
0
10
20
30
40
50
60
70
80

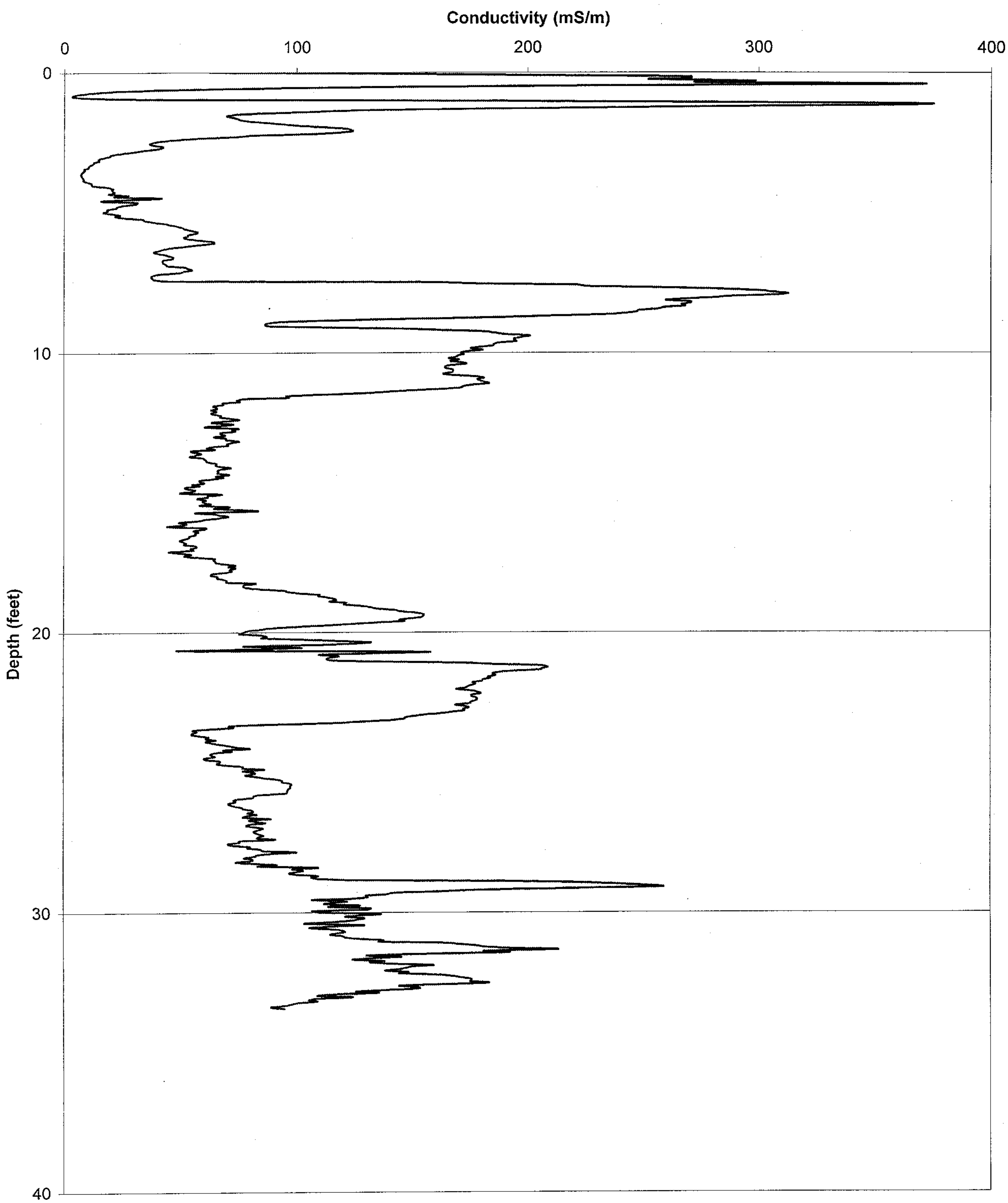
Soil Conductivity at Location 367 (duplicate)



Soil onductivity at Location 368



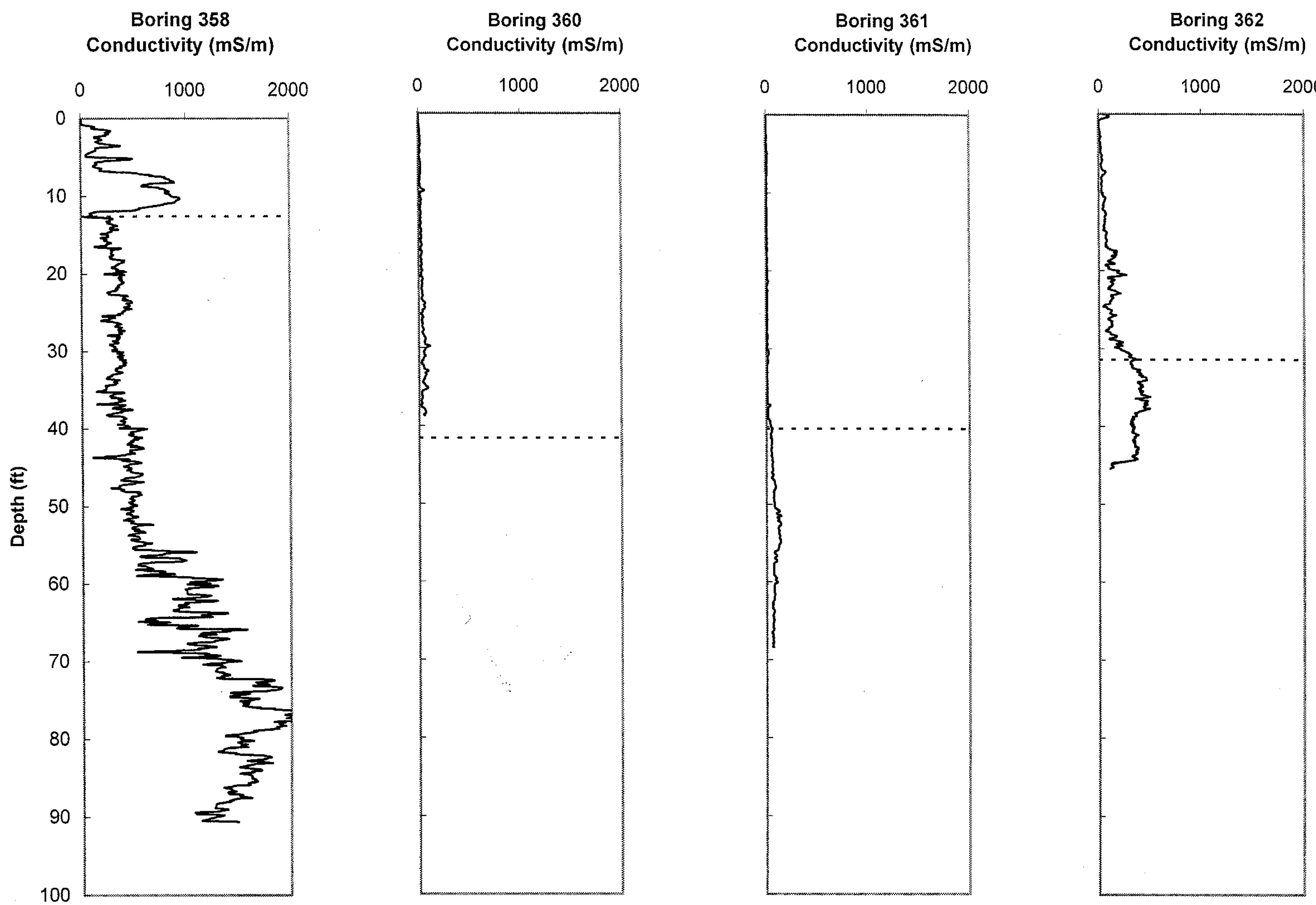
Soil Conductivity at Location 369



Attachment 6

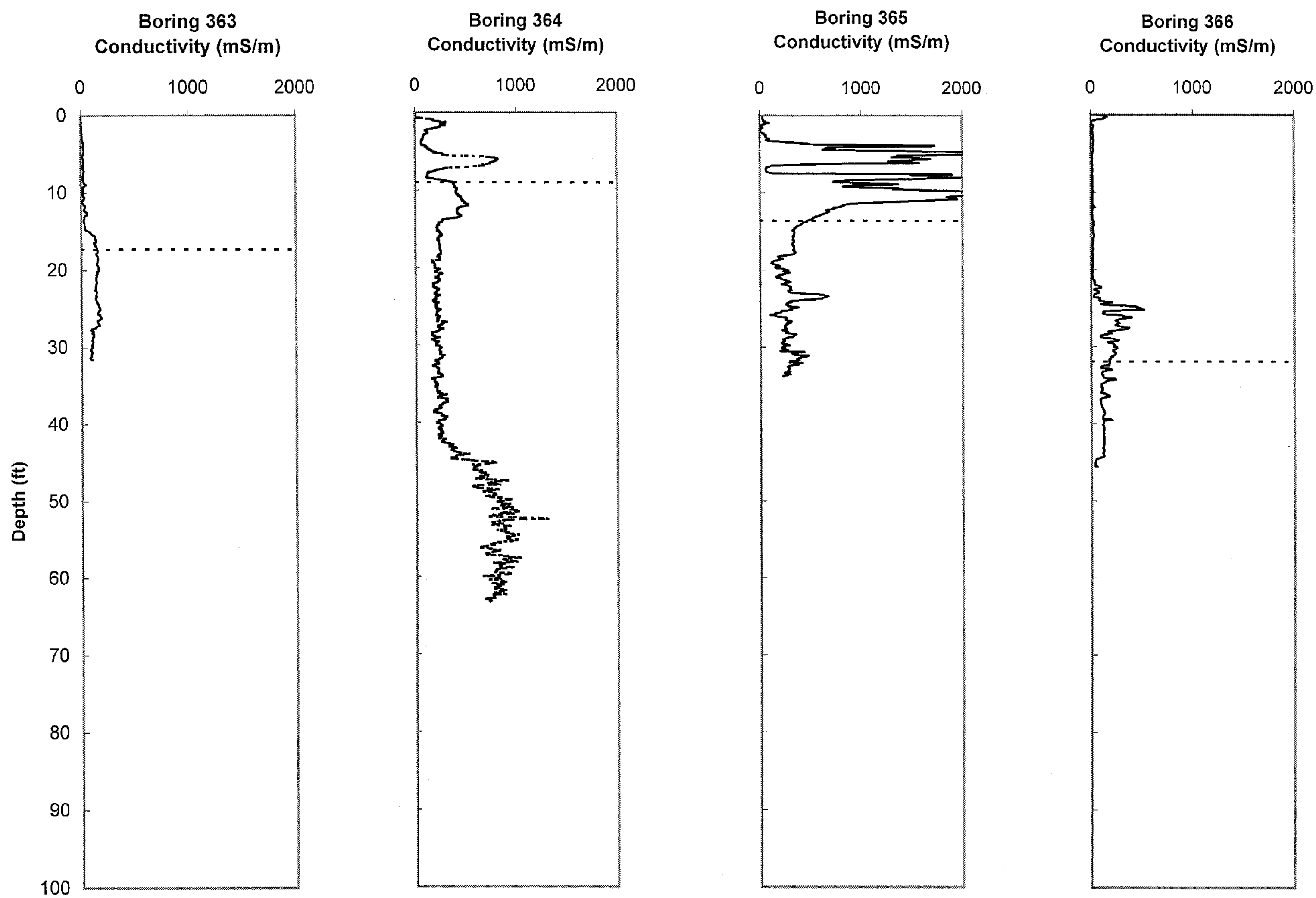
Combined Soil Conductivity Profiles

Soil Conductivity - 2000 mS/m Full Scale



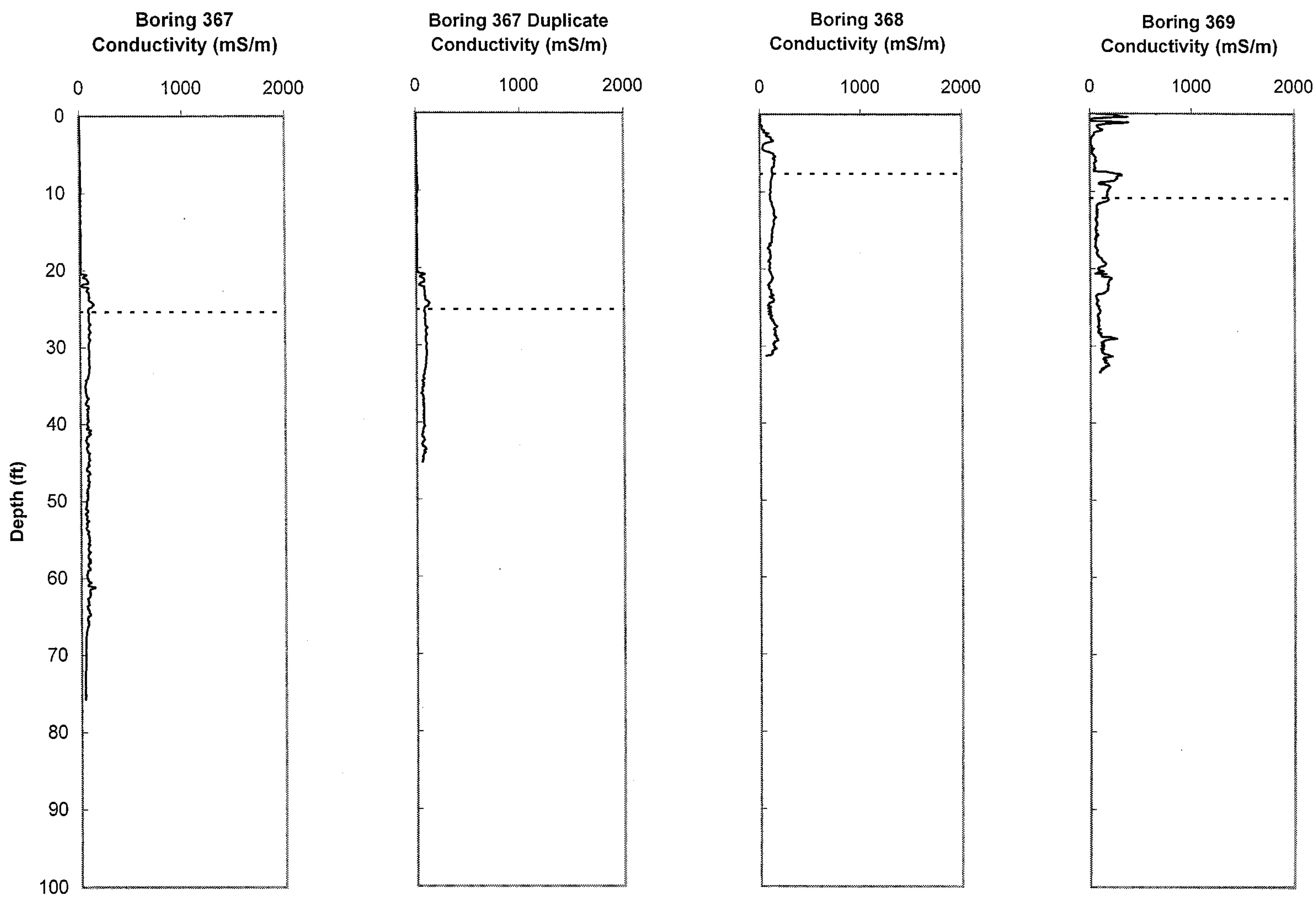
----- indicates water level

Soil Conductivity - 2000 mS/m Full Scale



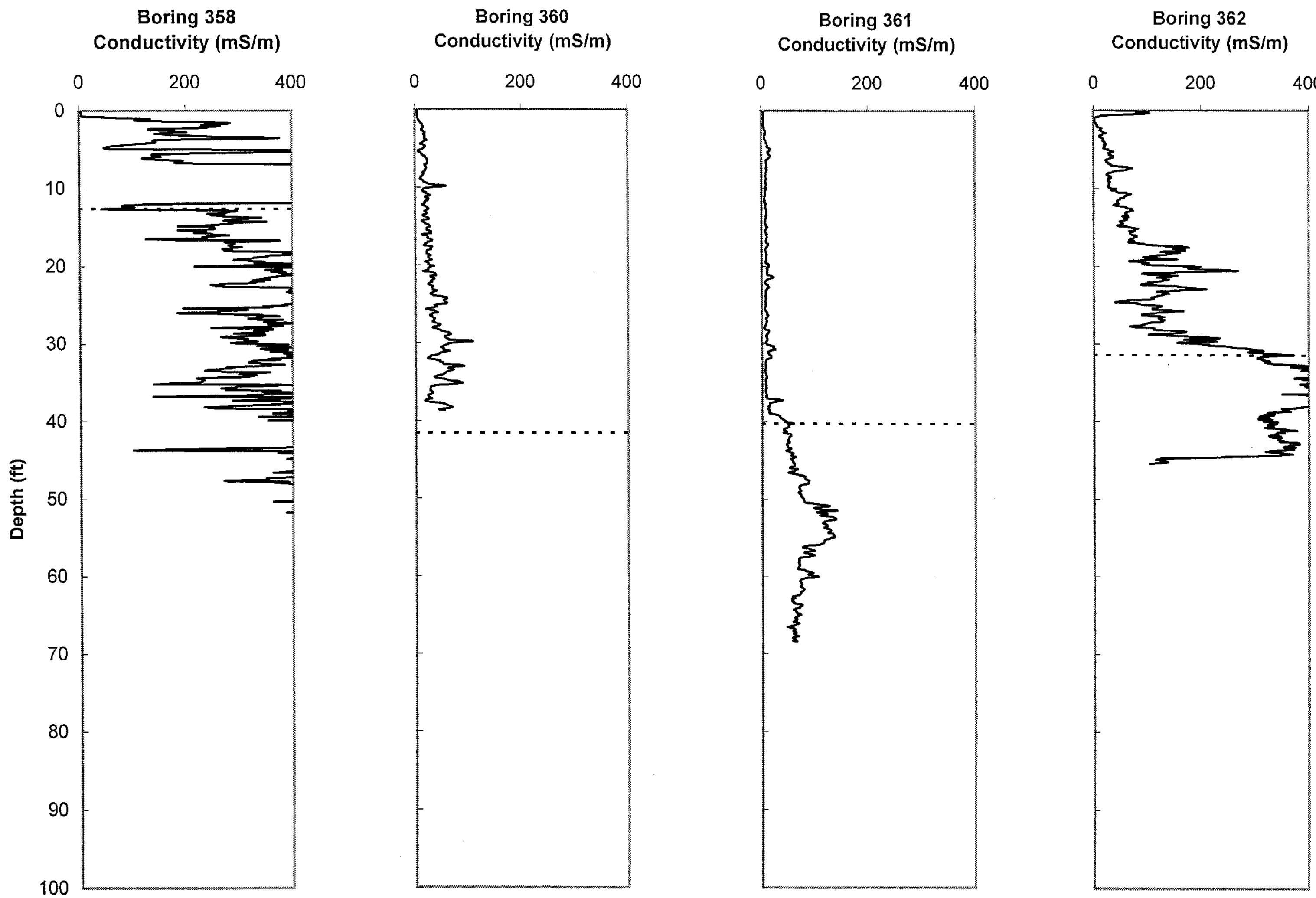
----- indicates water level

Soil Conductivity - 2000 mS/m Full Scale



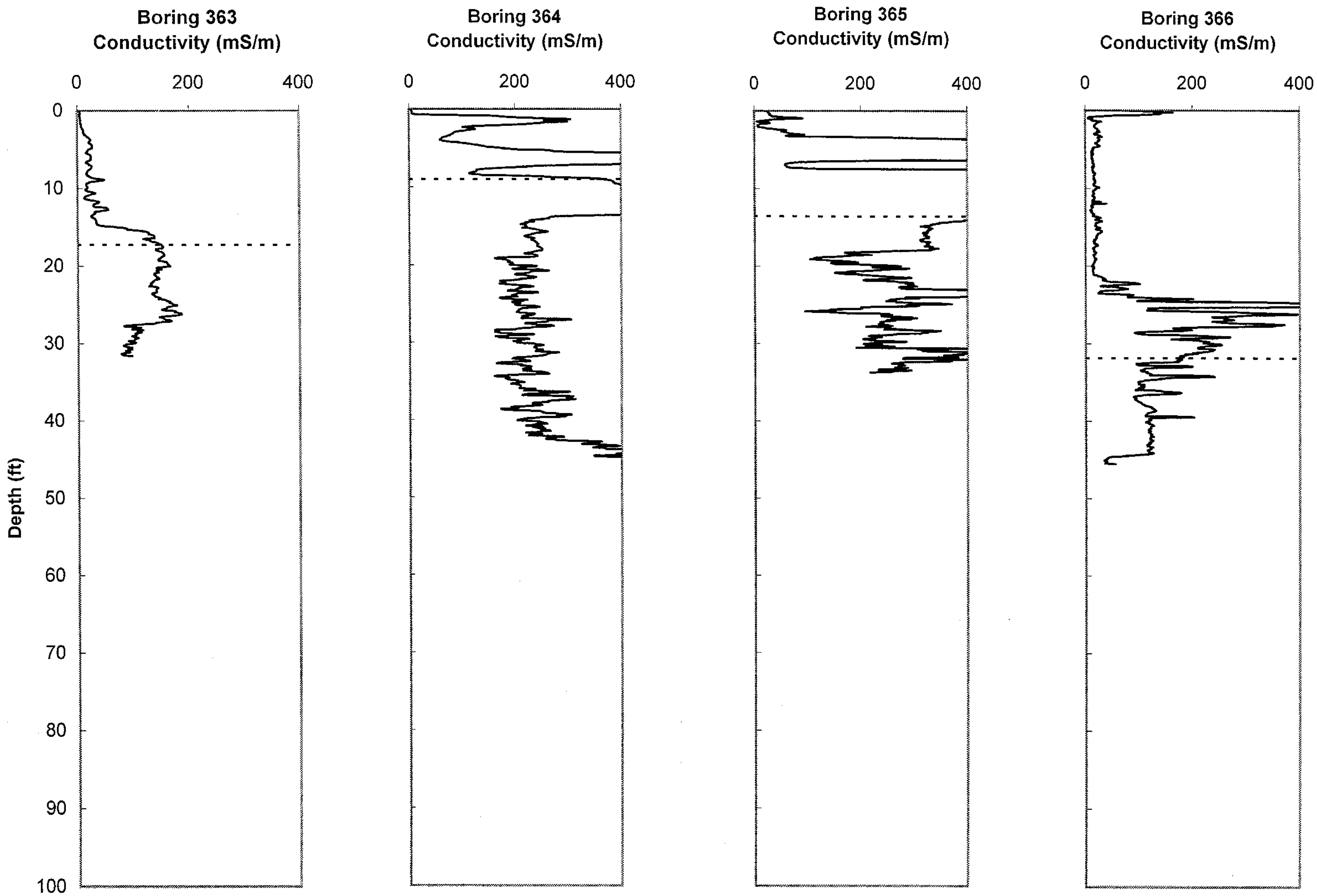
----- indicates water level

Soil Conductivity - 400 mS/m Full Scale



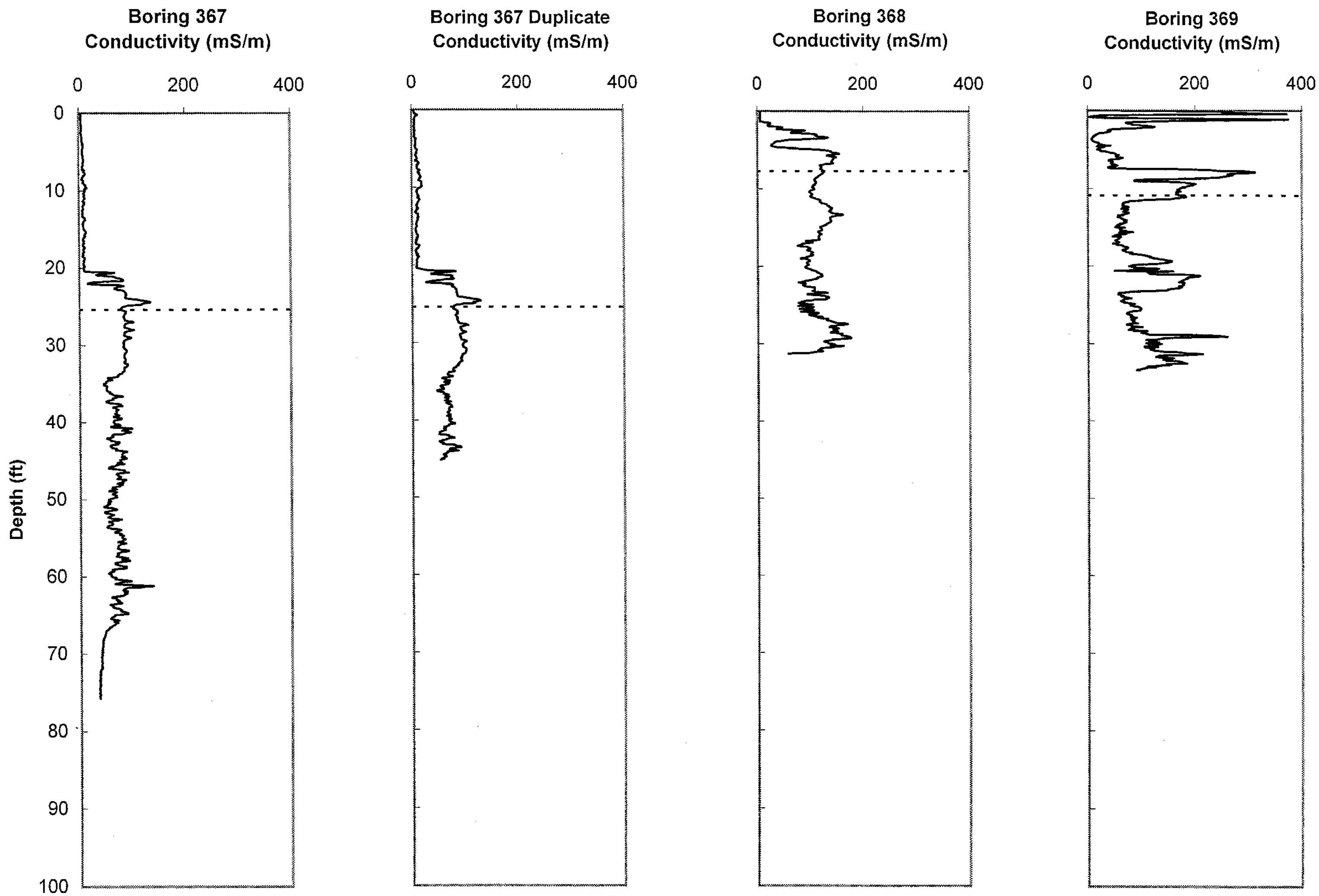
----- indicates water level

Soil Conductivity - 400 mS/m Full Scale



----- indicates water level

Soil Conductivity - 400 mS/m Full Scale



----- indicates water level

Attachment 7

Water Sampling Results

GROUND WATER QUALITY DATA BY LOCATION (USEE100) FOR SITE MOA01, MOAB
LOCATION: 0362 <borehole> Soil Conductivity Measurement depth to 45.45'; water sampling depth to 55'
REPORT DATE: 10/31/2002 7:45 am

PARAMETER	UNITS	SAMPLE: DATE	ID	DEPTH RANGE (FT BLS)	RESULT	QUALIFIERS: LAB	DATA	QA	DETECTION LIMIT	UN-CERTAINTY
Ammonia, Total reported as NH3	mg/L	07/13/2002	0001	38.00 - 39.00	1	U			1	-
	mg/L	07/13/2002	0002	54.00 - 55.00	1	U			1	-
Chloride	mg/L	07/13/2002	0001	38.00 - 39.00	1200				-	-
	mg/L	07/13/2002	0002	54.00 - 55.00	1775				-	-
Density	g/cm3	07/13/2002	0001	38.00 - 39.00	0.9991				-	-
	g/cm3	07/13/2002	0002	54.00 - 55.00	1.0002				-	-
Specific Conductance	umhos/cm	07/13/2002	0001	38.00 - 39.00	6710				-	-
	umhos/cm	07/13/2002	0002	54.00 - 55.00	9550				-	-
Sulfate	mg/L	07/13/2002	0001	38.00 - 39.00	808				-	-
	mg/L	07/13/2002	0002	54.00 - 55.00	1422				-	-
Temperature	C	07/13/2002	0001	38.00 - 39.00	10.6				-	-
	C	07/13/2002	0002	54.00 - 55.00	10.3				-	-
Total Dissolved Solids	mg/L	07/13/2002	0001	38.00 - 39.00	3480				-	-
	mg/L	07/13/2002	0002	54.00 - 55.00	5567				-	-
Uranium	mg/L	07/13/2002	0001	38.00 - 39.00	0.0276				-	-
	mg/L	07/13/2002	0002	54.00 - 55.00	0.0146				-	-

GROUND WATER QUALITY DATA BY LOCATION (USEE100) FOR SITE MOA01, MOAB
LOCATION: 0362 <borehole> Soil Conductivity Measurement depth to 45.45'; water sampling depth to 55'
REPORT DATE: 10/31/2002 7:45 am

PARAMETER	UNITS	SAMPLE: DATE	ID	DEPTH RANGE (FT BLS)	RESULT	QUALIFIERS: LAB	DATA	QA	DETECTION LIMIT	UN-CERTAINTY

RECORDS: SELECTED FROM USEE100 WHERE site_code='MOA01' AND location_code in('0362','0364') AND (data_validation_qualifiers IS NULL OR data_validation_qualifiers NOT LIKE '%R%' AND data_validation_qualifiers NOT LIKE '%X%')

SAMPLE ID CODES: 000X = Filtered sample (0.45 µm). N00X = Unfiltered sample. X = replicate number.

LAB QUALIFIERS:

- * Replicate analysis not within control limits.
- \+ Correlation coefficient for MSA < 0.995.
- > Result above upper detection limit.
- A TIC is a suspected aldol-condensation product.
- B Inorganic: Result is between the IDL and CRDL. Organic: Analyte also found in method blank.
- C Pesticide result confirmed by GC-MS.
- D Analyte determined in diluted sample.
- E Inorganic: Estimate value because of interference, see case narrative. Organic: Analyte exceeded calibration range of the GC-MS.
- H Holding time expired, value suspect.
- I Increased detection limit due to required dilution.
- J Estimated
- M GFAA duplicate injection precision not met.
- N Inorganic or radiochemical: Spike sample recovery not within control limits. Organic: Tentatively identified compund (TIC).
- P > 25% difference in detected pesticide or Arochlor concentrations between 2 columns.
- S Result determined by method of standard addition (MSA).
- U Analytical result below detection limit.
- W Post-digestion spike outside control limits while sample absorbance < 50% of analytical spike absorbance.
- X Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Y Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Z Laboratory defined (USEPA CLP organic) qualifier, see case narrative.

DATA QUALIFIERS:

- F Low flow sampling method used.
- L Less than 3 bore volumes purged prior to sampling.
- U Parameter analyzed for but was not detected.
- G Possible grout contamination, pH > 9.
- Q Qualitative result due to sampling technique
- X Location is undefined.
- J Estimated value.
- R Unusable result.

QA QUALIFIER: # = validated according to Quality Assurance guidelines.

GROUND WATER QUALITY DATA BY LOCATION (USEE100) FOR SITE MOA01, MOAB
LOCATION: 0364 <borehole> Soil Conductivity Measurement
REPORT DATE: 10/31/2002 7:45 am

PARAMETER	UNITS	SAMPLE: DATE	ID	DEPTH RANGE (FT BLS)	RESULT	QUALIFIERS: LAB	DATA	QA	DETECTION LIMIT	UN-CERTAINTY
Ammonia, Total reported as NH3	mg/L	07/12/2002	0001	39.00 - 40.00	1	U			1	-
	mg/L	07/12/2002	0002	53.00 - 54.00	1	U			1	-
Chloride	mg/L	07/12/2002	0001	39.00 - 40.00	3626				-	-
	mg/L	07/12/2002	0002	53.00 - 54.00	8488				-	-
Density	g/cm3	07/12/2002	0001	39.00 - 40.00	1.0022				-	-
	g/cm3	07/12/2002	0002	53.00 - 54.00	1.01				-	-
Specific Conductance	umhos/cm	07/12/2002	0001	39.00 - 40.00	13870				-	-
	umhos/cm	07/12/2002	0002	53.00 - 54.00	26100				-	-
Sulfate	mg/L	07/12/2002	0001	39.00 - 40.00	1004				-	-
	mg/L	07/12/2002	0002	53.00 - 54.00	3074				-	-
Temperature	C	07/12/2002	0001	39.00 - 40.00	9.8				-	-
	C	07/12/2002	0002	53.00 - 54.00	10.5				-	-
Total Dissolved Solids	mg/L	07/12/2002	0001	39.00 - 40.00	7910				-	-
	mg/L	07/12/2002	0002	53.00 - 54.00	19220				-	-
Uranium	mg/L	07/12/2002	0001	39.00 - 40.00	0.0075				-	-
	mg/L	07/12/2002	0002	53.00 - 54.00	0.0079				-	-

GROUND WATER QUALITY DATA BY LOCATION (USEE100) FOR SITE MOA01, MOAB
LOCATION: 0364 <borehole> Soil Conductivity Measurement
REPORT DATE: 10/31/2002 7:45 am

PARAMETER	UNITS	SAMPLE: DATE	ID	DEPTH RANGE (FT BLS)	RESULT	QUALIFIERS: LAB	DATA	QA	DETECTION LIMIT	UN-CERTAINTY

RECORDS: SELECTED FROM USEE100 WHERE site_code='MOA01' AND location_code in('0362','0364') AND (data_validation_qualifiers IS NULL OR data_validation_qualifiers NOT LIKE '%R%' AND data_validation_qualifiers NOT LIKE '%X%')

SAMPLE ID CODES: 000X = Filtered sample (0.45 µm). N00X = Unfiltered sample. X = replicate number.

LAB QUALIFIERS:

- * Replicate analysis not within control limits.
- + Correlation coefficient for MSA < 0.995.
- > Result above upper detection limit.
- A TIC is a suspected aldol-condensation product.
- B Inorganic: Result is between the IDL and CRDL. Organic: Analyte also found in method blank.
- C Pesticide result confirmed by GC-MS.
- D Analyte determined in diluted sample.
- E Inorganic: Estimate value because of interference, see case narrative. Organic: Analyte exceeded calibration range of the GC-MS.
- H Holding time expired, value suspect.
- I Increased detection limit due to required dilution.
- J Estimated
- M GFAA duplicate injection precision not met.
- N Inorganic or radiochemical: Spike sample recovery not within control limits. Organic: Tentatively identified compund (TIC).
- P > 25% difference in detected pesticide or Arochlor concentrations between 2 columns.
- S Result determined by method of standard addition (MSA).
- U Analytical result below detection limit.
- W Post-digestion spike outside control limits while sample absorbance < 50% of analytical spike absorbance.
- X Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Y Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Z Laboratory defined (USEPA CLP organic) qualifier, see case narrative.

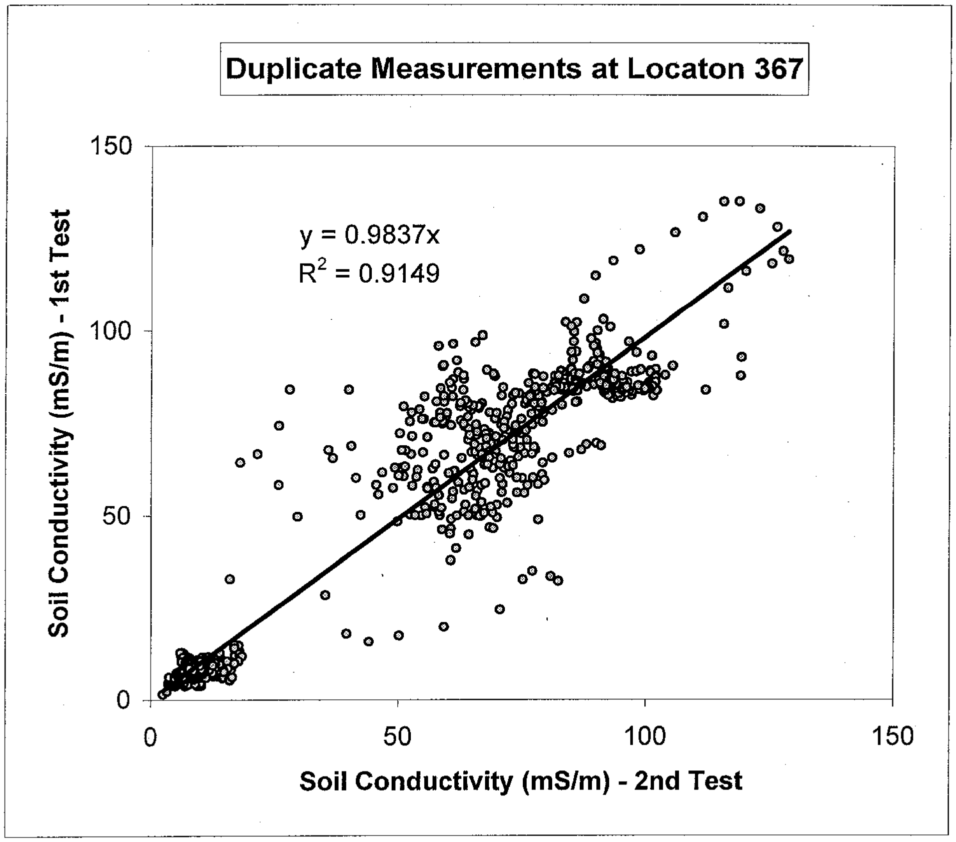
DATA QUALIFIERS:

- F Low flow sampling method used.
- L Less than 3 bore volumes purged prior to sampling.
- U Parameter analyzed for but was not detected.
- G Possible grout contamination, pH > 9.
- Q Qualitative result due to sampling technique
- X Location is undefined.
- J Estimated value.
- R Unusable result.

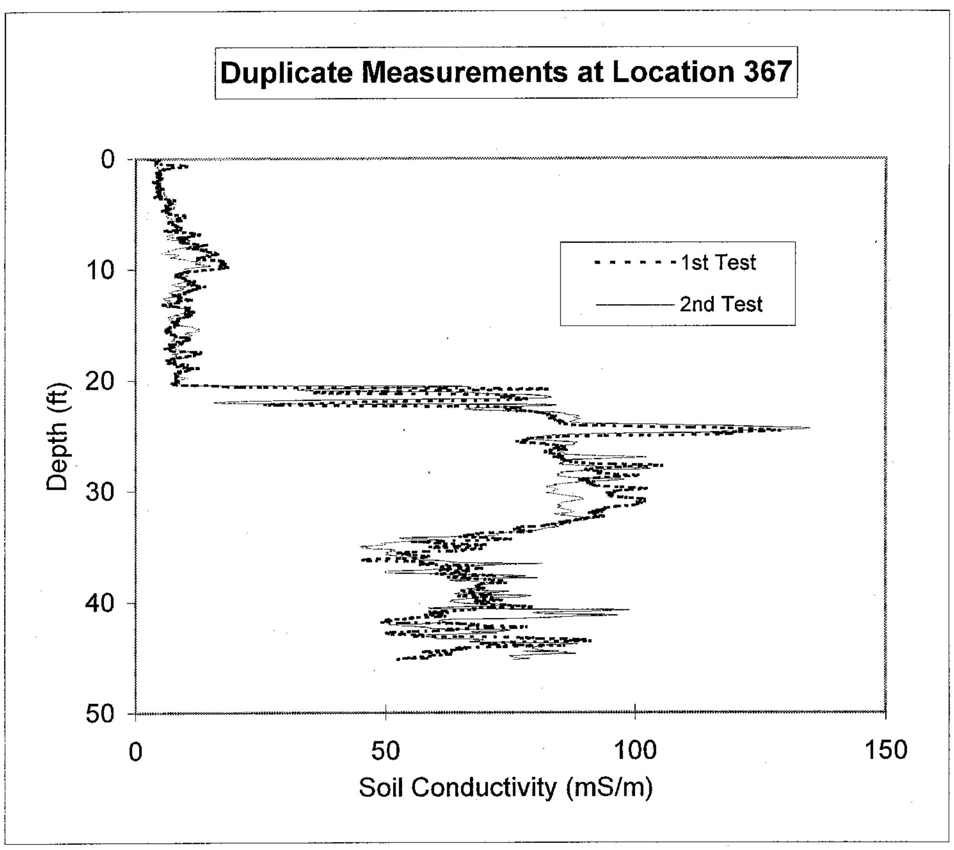
QA QUALIFIER: # = validated according to Quality Assurance guidelines.

Attachment 8

Reproducibility at Test Location 367



Duplicate Measurements at Locaton 367
y = 0.9837x
R^2 = 0.9149
Soil Conductivity (mS/m) - 1st Test
Soil Conductivity (mS/m) - 2nd Test
0
50
100
150

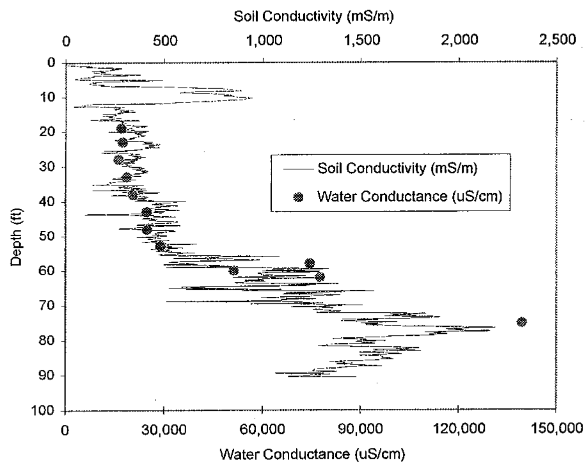


Duplicate Measurements at Location 367
1st Test
2nd Test
Depth (ft)
Soil Conductivity (mS/m)
0
10
20
30
40
50
100
150

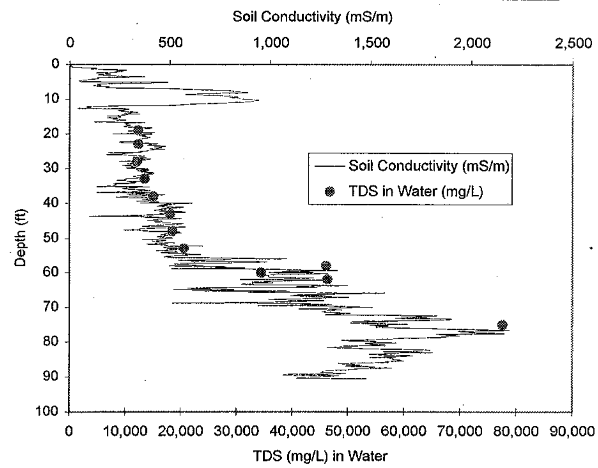
Attachment 9

Comparison of Soil Conductivity at Test Location 358 and Water Sampling Results Obtained From SMI–PW–01 Well Cluster

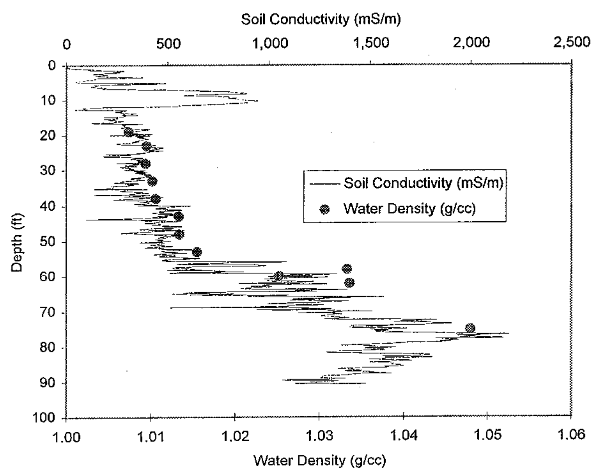
Comparison of Soil Conductivity (358) and Water Conductance (SMI-PW-01 Well Cluster)



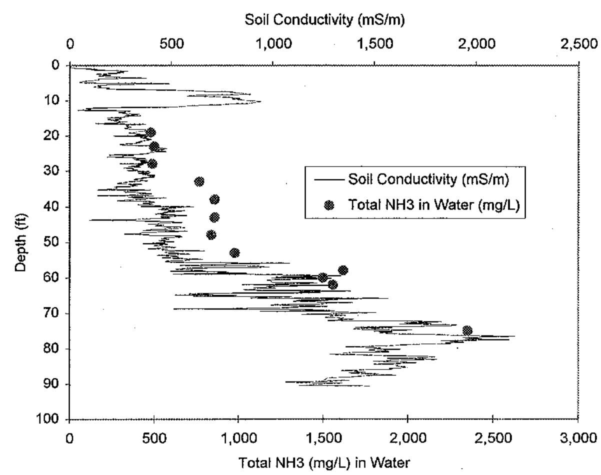
Comparison of Soil Conductivity (358) and TDS in Water (SMI-PW-01 Well Cluster)



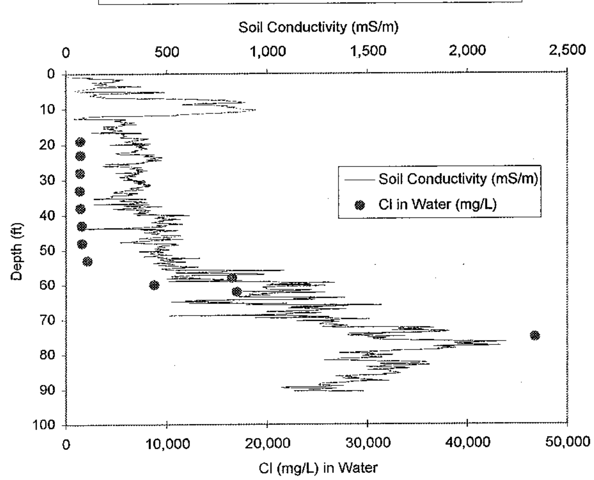
Comparison of Soil Conductivity (358) and Water Density (SMI-PW-01 Well Cluster)



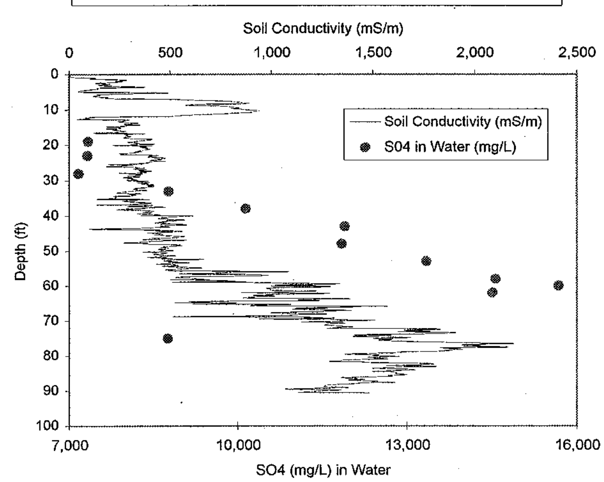
Comparison of Soil Conductivity (358) and Ammonia in Water (SMI-PW-01 Well Cluster)



Comparison of Soil Conductivity (358) and Chloride in Water (SMI-PW-01 Well Cluster)

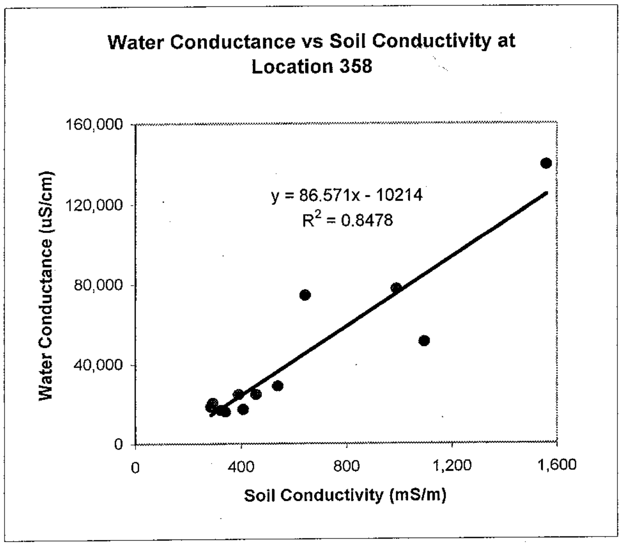


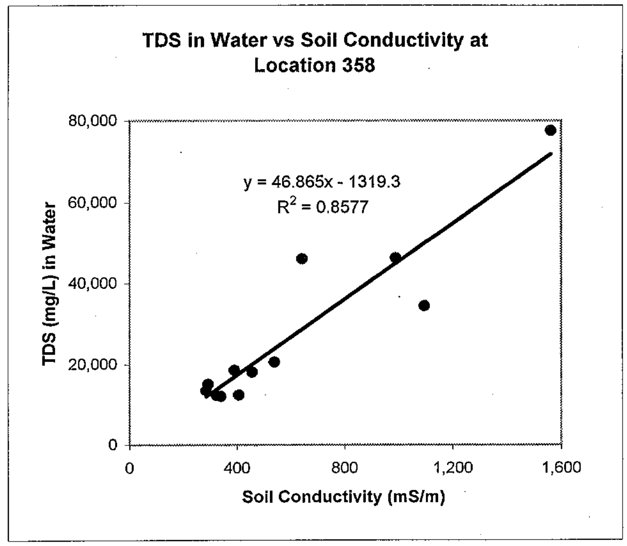
Comparison of Soil Conductivity (358) and Sulfate in Water (SMI-PW-01 Well Cluster)

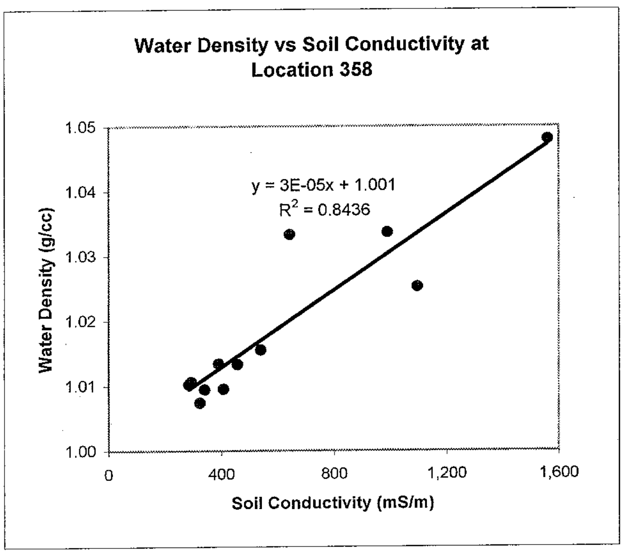


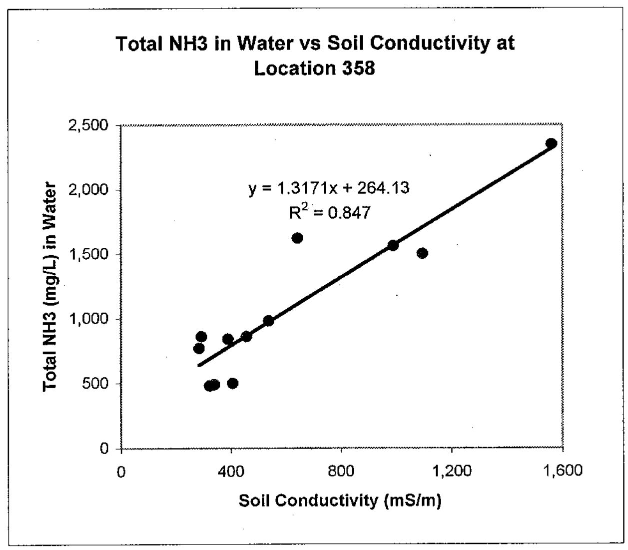
Attachment 10

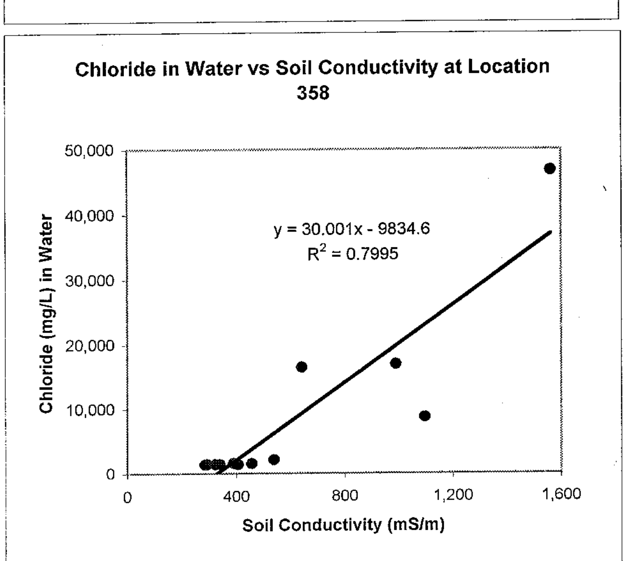
Correlation Plots Between Soil Conductivity at Test Location 358 and Water Sampling Results Obtained From SMI–PW–01 Well Cluster

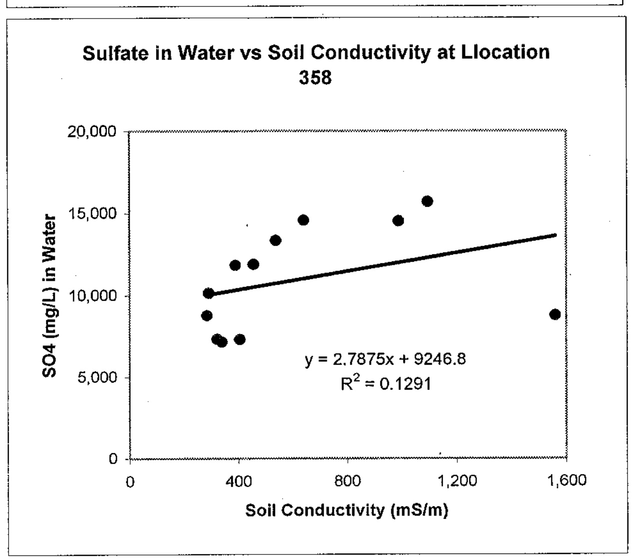

Water Conductance vs Soil Conductivity at Location 358
y = 86.571x - 10214
R2 = 0.8478
Water Conductance (uS/cm)
Soil Conductivity (mS/m)
0
40,000
80,000
120,000
160,000
400
800
1,200
1,600


TDS in Water vs Soil Conductivity at Location 358
y = 46.865x - 1319.3
R2 = 0.8577
TDS (mg/L) in Water
Soil Conductivity (mS/m)
0
20,000
40,000
60,000
80,000
400
800
1,200
1,600


Water Density vs Soil Conductivity at Location 358
y = 3E-05x + 1.001
R2 = 0.8436
Water Density (g/cc)
Soil Conductivity (mS/m)
1.00
1.01
1.02
1.03
1.04
1.05
0
400
800
1,200
1,600


Total NH3 in Water vs Soil Conductivity at Location 358
y = 1.3171x + 264.13
R2 = 0.847
Total NH3 (mg/L) in Water
Soil Conductivity (mS/m)
0
500
1,000
1,500
2,000
2,500
400
800
1,200
1,600


Chloride in Water vs Soil Conductivity at Location 358
y = 30.001x - 9834.6
R2 = 0.7995
Chloride (mg/L) in Water
Soil Conductivity (mS/m)
0
10,000
20,000
30,000
40,000
50,000
400
800
1,200
1,600


Sulfate in Water vs Soil Conductivity at Llocation 358
y = 2.7875x + 9246.8
R2 = 0.1291
SO4 (mg/L) in Water
Soil Conductivity (mS/m)
0
5,000
10,000
15,000
20,000
400
800
1,200
1,600